THE UNIVERSITY OF ALBERTA

AERATION AND CURING IN ASPHALT SAND STABILIZATION

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Aeration and Curing in Asphalt Sand Stabilization", submitted by Robert Charles White, in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Stabilization of soils in place with asphalt is currently being practiced by many agencies involved in modern highway construction. The problem of whether to aerate the mixture before compaction or not has been a valid one with authorities presenting arguments both for and against such practice. Also the length of time that the compacted mixture should be left to cure has varied in practice from a few days up to periods of thirty days with proponents for both.

In this investigation a uniformly graded fine-grained sand was mixed with three different percentages of a medium curing liquid asphalt at various water contents. Some mixtures were molded immediately after the mixing operation and others were allowed to aerate for from two to five hours at a temperature of $110^{\circ}F$ before being molded. Curing periods after molding of one, three and five days at a temperature of $110^{\circ}F$ were used and results compared. Cured samples were immersed in water for periods up to twenty-one days. Water absorption characteristics were determined together with immersed compressive strengths.

Aeration of the mixtures prior to compaction proved to be beneficial as measured by increased compressive strength after water immersion and decreased water absorption.

Curing for longer periods was highly beneficial for the aerated mixtures in terms of increased immersed compressive strength and lower water absorption. Although curing improved the immersed compressive strength of samples compacted immediately after mixing, no trend was established as far as decreased water absorption was concerned.

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CHAPTER I

INTRODUCTION

Dwindling supplies of suitable granular material for highway construction are increasing the need for attempting to modify the soil in place. Many soils if compacted at optimum moisture content will provide good load carrying capacity which unfortunately may be lost by subsequent absorption of moisture. In order to reduce infiltration of water with subsequent loss in strength of such soils they may sometimes be stabilized with asphalt. Soil-asphalt stabilization may be defined as the treatment of naturally occurring non-plastic or plastic soil materials with liquid asphalts at ordinary temperatures which after compaction will provide waterproof base or subbase courses of adequate load bearing qualities.

Two types of liquid asphalts namely cutback asphalt and emulsified asphalt, have been found to be suitable for mixing with soil at normal temperatures. The choice of amount and type of petroleum diluent in the cutback asphalt or the type and amount of emulsifying agent in the emulsified asphalt will depend largely upon the soil type, climate and construction practice to be followed. Regardless of the choice of liquid asphalt, one of the more pressing problems in the construction of such stabilized bases and subbases is a clear understanding of the role that water plays both before and after compaction. Since current construction practice covers a wide range of compacting water contents and curing periods, and laboratory studies give conflicting results (Pennell (1962))* it is considered

* References are cited by indicating the author and the year of publication. The references are contained in the bibliography at the conclusion of this thesis.

that further investigation of this aspect is warranted.

Purpose of the Investigation

The purpose of this investigation was to undertake a laboratory testing programme to study the effect of water content on the compressive strength, dry density, and durability of cutback asphalt stabilized sand.

Due to the large number of factors which influence the strength and durability of soil bituminous mixtures any single investigation must necessarily restrict the number of variables as much as possible. Therefore in this investigation only one type of sand and cutback asphalt was used. Also one method of mixing, compacting and curing was maintained throughout the testing programme.

The unconfined compression test was used to measure the strength of samples after curing and after immersion in water for various periods. This test was chosen for its simplicity and on the basis of Jones (1962) recommendation that such tests gave a satisfactory indication of durability.

Organization of the Thesis

The second chapter briefly outlines current theory on the role of cutback asphalt and water in sand stabilization. Favoured methods of evaluating durability are mentioned.

Chapter three describes the materials and outlines the scope of the test programme.

In the fourth chapter the various methods of preparing the test specimens are described as well as strength and immersion test procedures. In addition a brief resume of the analysis of the data is presented.

Chapter five includes the test results and discussion of their significance.

The final chapter presents the conclusions and recommendations made from the results of the test programme.

The appendices contain preliminary test results, sample data and calculation sheets and results of the main testing programme not considered of sufficient significance to be included in the main body of the thesis.

CHAPTER II

SAND ASPHALT STABILIZATION

The Stabilization Process

The theories advanced by Endersby (1942) explaining the role of the asphalt in the stabilization of soils still appear to be acceptable in the light of present knowledge. The so-called "plug" theory implies that the capillaries in the soil structure are plugged with asphalt thus preventing movement of water into or out of the system. Under the "intimate mix" theory, individual soil particles are presumeably coated with a thin film of asphalt which also effectively, prevents movement of water through the soil structure.

In order to stabilize a cohesionless soil two requirements must normally be filled. The soil structure must be provided with cohesion for strength and water resistance for stability. The degree to which these conditions are met will depend upon many variables such as: the amount of water present during mixing; the temperature, duration and type of mixing process; the properties of the soil; the properties of the bituminous stabilizer; the amount of water present during compaction; the method and degree of compaction and curing.

The Role of the Water

The importance of having sufficient water in the mix for a good distribution of asphalt has been known for many years. Work by Benson and Becker (1942), Cape (1940) and others showed that water facilitated the even distribution of the asphalt throughout the mix. Andrews and Noble (1949) found that the addition of water to soil decreased the

contact angle between the asphalt and the soil thus permitting better spreading of the asphalt throughout the mix.

In addition to aiding in the uniform distribution of asphalt throughout the mix, water assists in the compaction process. Katti,et al (1960) reported that soil-asphalt mixtures were usually more stable when compacted immediately after mixing. However the amount of mixing water for maximum dispersion of asphalt did not produce the most desirable stability properties of the compacted mixture. The percentage of mixing water required to produce maximum strength, maximum density, minimum total moisture absorption, and minimum expansion in the compacted specimens was found to be different for each property mentioned. Katti suggested the selection of a compromise moisture content for mixing at which the variance of each of the properties from the optimum value was a minimum. This compromise moisture content was found to be in close agreement with the optimum moisture content required for maximum dry density of the soil-asphalt-water mixture. Work done by Knowles (1962) indicated that minimum water absorption occurred at a molding water content close to the optimum for Standard AASHO dry density. However the relationship between maximum dry density and maximum strength was inconclusive.

Herrin (1958) found when comparing the stability of soil bituminous mixtures with unit weight, that large amounts of water and volatiles in the mixture increased the dry density but decreased the stability. The drier mixtures were found to provide better stability even though the dry density was lowered.

Influence of the Mixing Operation

The fact that the mixing operation influences the properties of the resultant soil bituminous product has been known for many years. Benson and Becker (1942) and Endersby (1942) observed that there appeared to be an optimum mixing time for any one soil, asphalt and water content. This optimum appeared to be from one to two minutes. Mixing times of lesser duration than the optimum merely distributed the asphalt throughout the mixture in large masses having little water proofing value. Mixing times of longer duration were found to cause predominantly intimate mix conditions in which the groups of soil particles were further broken down and the asphalt became distributed too thinly for good water proofing. However the type of mixer used also affected the stability of the resultant mix. The pugmill type mixer showed a definite optimum mixing time for any one mixture. The kitchen type mixer did not produce the same results but appeared to increase the stability of the final product with longer mixing periods. The amount of asphalt in the mixture did not materially affect the optimum mixing time found with pugmill type mixing. Mixing water content affected the optimum mixing time to a much greater extent. At higher water contents the curve of stability versus mixing time is relatively flat over a range of mixing times from $\frac{1}{2}$ to 2 minutes. At lower mixing water contents this curve shows a fairly sharp peak at an optimum mixing time of about one minute. From the mixing time control standpoint therefore it would appear to be good practice to mix at higher water contents.

There are so many variables that affect the mixing operation that for any laboratory testing programme as many as possible must be made constant. In this investigation the water and sand were mixed prior

to the addition of the MC3 cutback asphalt. Total mixing time for the cutback-sand-water mix was $2\frac{1}{2}$ minutes and a twin shaft pugmill was used.

Durability and Strength of Asphalt Stabilized Sand

A recent investigation completed by Jones (1962) on durability testing of bituminous stabilized sand showed that the most severe test of the durability of the final product was water immersion. His observation that the unconfined compressive strength of the specimen after an immersion period of seven days could be used as an indication of its durability is similar to findings by other investigators. Rice and Goetz (1949) attempted to correlate the compressive strength of specimens after immersion in distilled water at 110°F for five days, with Hubbard - Field Stability. As a result of this latter study they concluded that a suitable mixture would be one having a compressive strength of not less than 60 psi after five days immersion at 110°F. This corresponded roughly to a Hubbard - Field Stability value of 1000 lb at a testing temperature of 77°F. Knowles (1962) found that a Modified Hubbard - Field Stability value of 1000 lb corresponded to an unconfined compressive strength value of between 10 and 15 psi. However specimen size, testing temperature and molded dry density were not the same as used by Rice so no direct comparison can be made. Also the period of immersion of specimens allowed by Knowles was 42 days at room temperature as compared to 5 days at 110°F used by Rice.

Winterkorn (1957) suggested that the unconfined compressive strength of soil-bitumen specimens after seven days immersion in distilled water should be greater than 75 psi for the mixture to be suitable for base construction. If several mixtures fulfill this require-

ment, the one having the highest ratio between wet and dry compress-
ive strength should be selected.

CHAPTER III

THE TESTING PROGRAMME

Materials

Soil: The soil used was a fine sand obtained from the Alberta Department of Highways McGinn Pit No.2 which is located about 20 miles west of Edmonton. This pit was selected as the soil source because of the previous work done by Jones (1962) and Pennell (1962) on this sand.

The batch sample was quartered and split for sieve analyses by the Department of Highways and stored in bags. Sand used in the testing programme was taken directly from the bags without further mixing or splitting. The gradation of the sand is shown in Table I. The relatively low uniformity coefficient (Cu) of 2.00 indicates a sand that is quite uniformly graded. A uniformity coefficient of 2.33 was obtained by Jones on the same type of sand. The Standard AASHO maximum dry density and optimum water content were determined to be 103.2 pounds per cubic foot and 13.6 percent respectively.

The average water content of the bagged sand was determined to be 0.5 percent.

Asphalt: The asphalt used in this investigation was a medium curing liquid asphalt, designated MC3, obtained from Husky Oil and Refining Ltd., Lloydminster, Saskatchewan. An analysis of this material as supplied by the manufacturer is shown in Table II.

Water: Distilled water was used in preparing the samples whereas tap water was used to fill the tanks for the immersion testing. Temperature of the fresh tap water was approximately 65°F which increased

TABLE I

SAND PROPERTIES

Unified Classification	SP
AASHO Classification	A-3
Standard AASHO dry density	103.2 pcf
Optimum water content (Standard AASHO)	13.6%
Specific gravity	2.66
Uniformity Coefficient (Cu)	2.00

Grain Size Distribution

US Standard Sieve Size	Percent Passing
10	100
20	100
40	99.0
60	69.5
100	19.1
200	2.7

TABLE II

ASPHALT PROPERTIES

Product	MC3 Cutback Asphalt
Specific Gravity at 60°F	0.9826
API Gravity at 60°F	12.5
Flash TOC	150 ≠ °F
Water	Nil %
Saybolt Furol Visosity @ 140°F	409 seconds

Distillation:

	% of Total Over At	% of Distillate Total Over
374°F		
437°F	0	0
500°F	2	10.0
600°F	14	70.0
680°F	20	100.0

% Residue to 680°F volume by difference 80.0

Residue :	Penetration @ 77°F (100 grams. 5 seconds)	173
	Oliensis Spot Test (15% Xylene)	Negative
	Soluble in Carbon Tetrachloride	99.8 ≠ %
	Ductility @ 77°F (5 cm. per minute)	

to approximately room temperature of 70°F within a few hours after standing in the immersion tanks.

Scope of The Testing Programme

Preliminary: Some preliminary testing was undertaken to establish procedures for the main testing programme. Data from the preliminary testing is included in Appendix A.

A compaction test of the sand was carried out using a 2 inch diameter by 4 inch high cylindrical mold. The compactive effort used was as determined by the Research Council of Alberta as giving comparable results to Standard AASHO. This procedure consisted of compacting in 4 layers with 10 blows per layer of a 5.5 lb rammer falling a height of 12 inches. The compactive effort so induced is 30,300 foot pounds per cubic foot compared to 49,500 foot pounds per cubic foot required by Jones (1962) for the 2 inch diameter by 2 inch high specimens. Compactive effort using a 4 inch diameter by 4.59 inch high Standard AASHO mold is 12,400 foot pounds per cubic foot.

A mix of 5 percent MC3 (by weight of oven dried sand) and 15 percent water was prepared using a pugmill mixer. Twenty four specimens were molded from the mix immediately after mixing using the mold and compactive effort outlined above. These specimens were cured in a constant temperature oven at 110°F for periods ranging from 0 to 170 hours and then subjected to unconfined compression tests. From the graph of unconfined compressive strength versus curing period, the curing times of 24 hours, 72 hours and 120 hours were selected for the main testing programme.

The mix was allowed to dry in the bag* for one day at room temperature of 70°F and then eight specimens were prepared and cured at

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* After mixing, the cutback-sand-water mixture was stored in a polyethylene bag.

$110^{\circ}F$ for periods up to $189\frac{1}{2}$ hours. The unconfined compressive strengths of these specimens were found to be lower than those that had been molded immediately after mixing. It was therefore decided to include aerating or drying back in the main testing programme.

Main Programme Outline: The major portion of the programme consisted of measuring the water absorption and unconfined compressive strengths of specimens cured for 24, 72 and 120 hours at $110^{\circ}F$ and immersed in water up to 21 days.

Thirty six specimens were prepared for each batch of four different water contents and MC3 contents of 2 and 4 percent. Three specimens were used for each unconfined compression test at the various curing and immersion periods.

In addition, twelve specimens were prepared at a water content of 5 percent and MC3 content of 2 percent and subjected to curing periods of 24 hours and 120 hours and an immersion period of seven days.

Twelve specimens were also prepared for each batch of four different water contents and an MC3 content of 1 percent. Curing periods of 24 hours and 120 hours duration were used and immersion period of seven days.

Batches were then prepared for each of the three MC3 contents (1, 2 and 4 percent) and mixed at the highest water content used previously. The mixes were dried-back (aerated) for 2 and 5 hour periods at $110^{\circ}F$ after which times twelve specimens were molded and subjected to curing periods of 24 and 120 hours and an immersion period of seven days. Unconfined compression tests were conducted as on the previous specimens. An outline of the test programme is given in Table III.

TABLE III

TEST PROGRAMME OUTLINE

Batch No.	Mixing MC3 %	Mixing Water %	Aeration Period hrs	Curing Period hrs	Immersion Period days	Comp. Strength Samples	Total Samples
1	5	15	0	up to 170	0	24	24
1a	5	15	24	up to 190	0	8	8
2	4	15	0	24	0,7,14,21	12	
				72	"	"	
				120	"	"	36
3	4	13	0	24	0,7,14,21	12	
				72	"	"	
				120	"	"	36
4	4	11	0	24	0,7,14,21	12	
				72	"	"	
				120	"	"	
5	4	9	0	24	0,7,14,21	12	
				72	"	"	
				120	"	"	36
6	2	10	0	24	0,7,14,21	12	
				72	"	"	
				120	"	"	36
7	2	12	0	24	0,7,14,21	12	
				72	"	"	
				120	"	"	36
8	2	14	0	24	0,7,14,21	12	
				72	"	"	
				120	"	"	36
9	2	16	0	24	0,7,14,21	12	
				72	"	"	
				120	"	"	36
10	2	$5\frac{1}{2}$	0	24	0 and 7	6	
				120	"	"	12
11	1	5	0	24	0 and 7	6	
				120	"	"	12
12	1	10	0	24	0 and 7	6	
				120	"	"	12
13	1	15	0	24	0 and 7	6	
				120	"	"	12
14	1	18	0	24	0 and 7	6	
				120	"	"	12
15	2	16	2	24	0 and 7	6	
				120	"	"	
			5	24	"	"	
				120	"	"	24

TABLE III (continued)

Batch No.	Mixing MC3 %	Mixing Water %	Aeration Period hrs	Curing Period hrs	Immersion Period days	Comp. Strength Samples	Total Samples
16	1	18	2	24	0 and 7	6	
				120	"	"	
			5	24	"	"	
				120	"	"	24
17	4	15	2	24	0 and 7	6	
				120	"	"	
				24	"	"	
				120	"	"	24
				Total test samples			452

The optimum water content of the sand using the Research Council compaction procedure previously described, was found to be 18 percent. For this reason the mixtures of cutback asphalt and sand were designed using a total liquid (cutback asphalt plus water) content of about 18 percent for the wettest mix. It was anticipated that this procedure would enable maximum dry densities to be reached for each of the three cutback contents selected, however as shown in Figure 12 maximum dry density was only attained for the mixtures containing one percent cutback and this was not discovered until the testing programme had been completed.

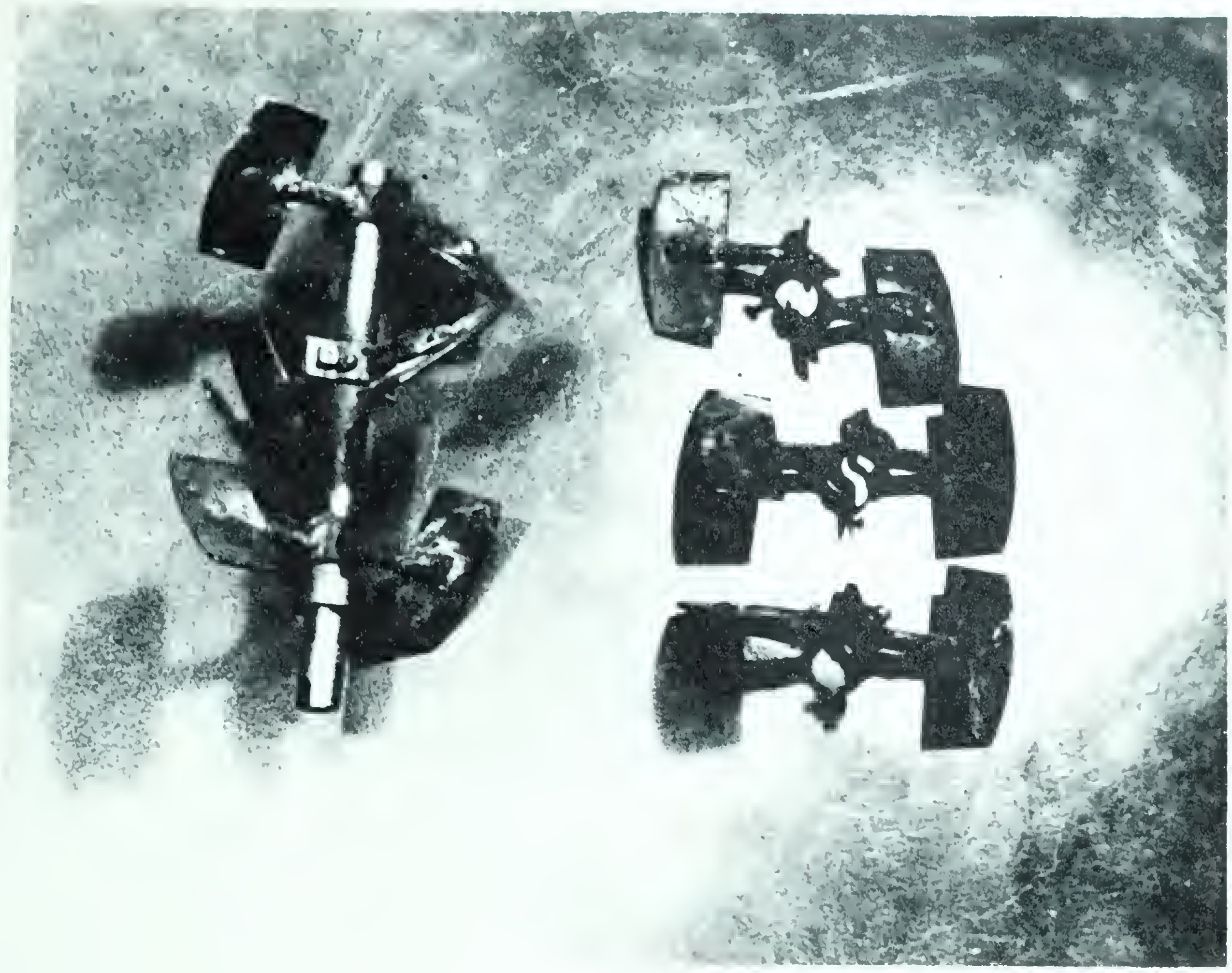
CHAPTER IV

TESTING PROCEDURES

Mixing of the Materials

A Hobart kitchen mixer was used for mixing of the sand and water for the moisture density tests in the preliminary testing. It was found to be of insufficient capacity to mix the 40 lb batches of materials that would be required for the main testing programme. Therefore a pugmill type mixer was used for all batches containing cutback asphalt. The preliminary batch containing 5% MC3 and 15% water was mixed with three pairs of mixing paddles on each shaft, mounted as shown in the upper photograph of Plate I. As the pugmill was also being used to mix coarse aggregate and asphalt mixes, these relatively large mixing paddles were continually breaking off from the shafts. Two new shafts with paddles mounted as shown in the lower photograph of Plate I were therefore installed in the mixer. All of the batches produced for the main testing programme were mixed in the pugmill with these paddles.

The procedure for mixing consisted first of weighing out the required amount of air dried sand. The amount of distilled water for mixing was determined on the basis of the oven dried weight of the sand. The amount of water to add was this amount less the water content of the sand. The water was added to the sand in the pugmill and mixed for two minutes. The mixture was then allowed to stand for about five minutes. The MC3 cutback asphalt was heated to a temperature of approximately 175°F in a thermostatically controlled asphalt



PADDLES USED FOR MIXING PRELIMINARY BATCH

INTERIOR OF PUGMILL
SHOWING MIXING PADDLES USED FOR MAIN TEST PROGRAMME

PLATE I

heating kettle. An amount of MC3, Based on the desired percentage of the oven dried weight of sand, was weighed out directly from the heating kettle into a separate container. This was then added to the sand-water mix while the pugmill was in operation. The addition of the hot MC3 to the mix was completed in approximately one half minute. The lid of the pugmill was then closed and mixing continued for one minute. Mixing was then stopped, sides of the pugmill were scraped & mixing continued for an additional minute. Scraping of the sides of the pugmill was found to be necessary after the paddles were redesigned owing to the larger clearance between side walls and paddle tips. The mixed material was dumped out of the bottom of the pugmill into the metal tray, which can be seen in the upper photograph of Plate II and immediately transferred to a polyethylene plastic bag to prevent loss of volatiles. Mixes that were aerated were transferred to drying pans, instead of the plastic bag, and placed in an oven at 110^{O}F to dry for either a two or five hour period. Volatile content* samples were taken from these latter mixes immediately after the mixing operation. The mixes being aerated were stirred once during the drying period. After the period of aeration was completed, the mixture was transferred to a polyethylene plastic bag and allowed to stand for one hour to facilitate uniform moisture conditions. Some examples of mix design are included in Appendix C.

Molding the Samples

Samples were molded either immediately after mixing, if no aeration was to be allowed, or one hour after drying back for the desired aeration period. One volatile content sample was taken for every 12

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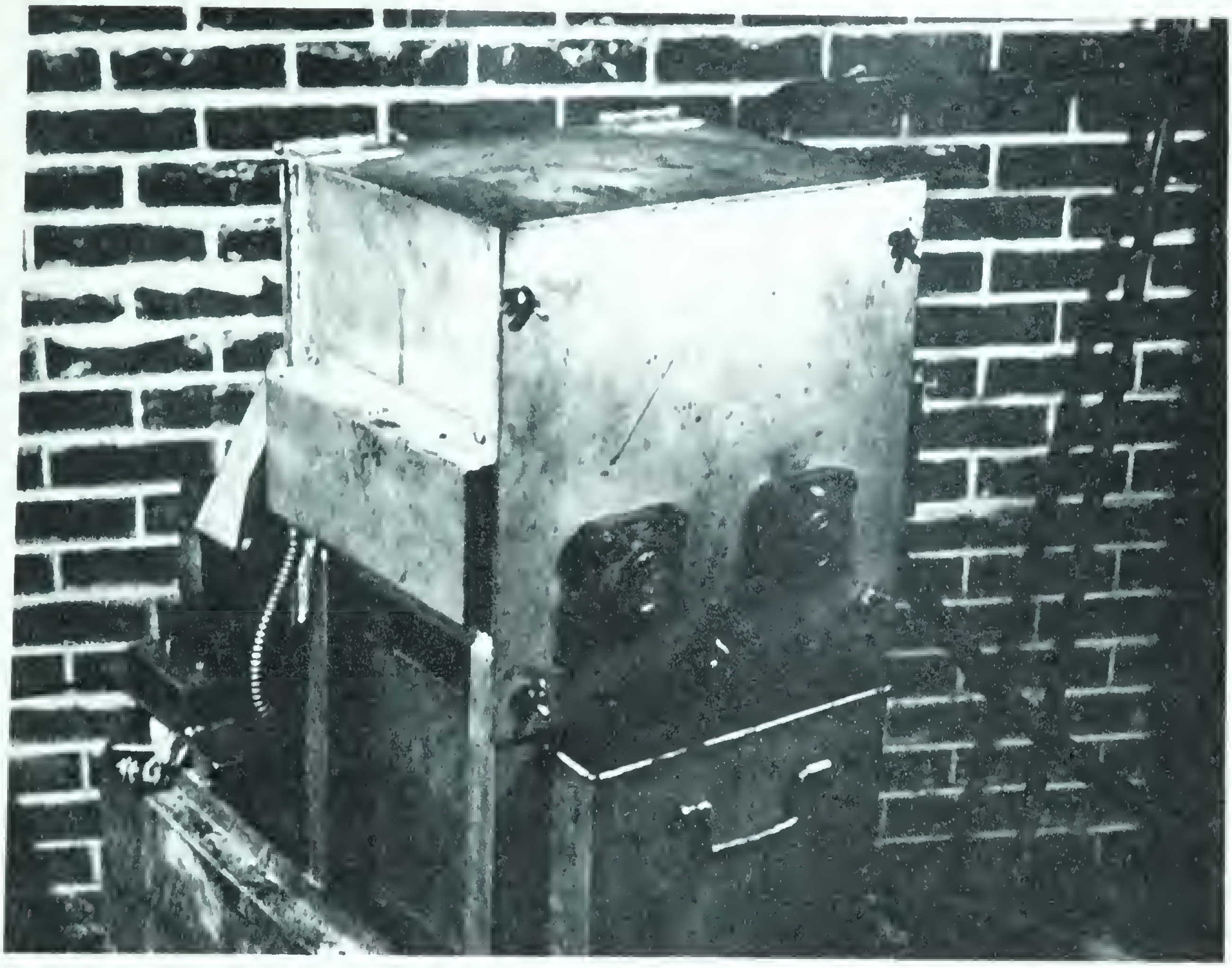
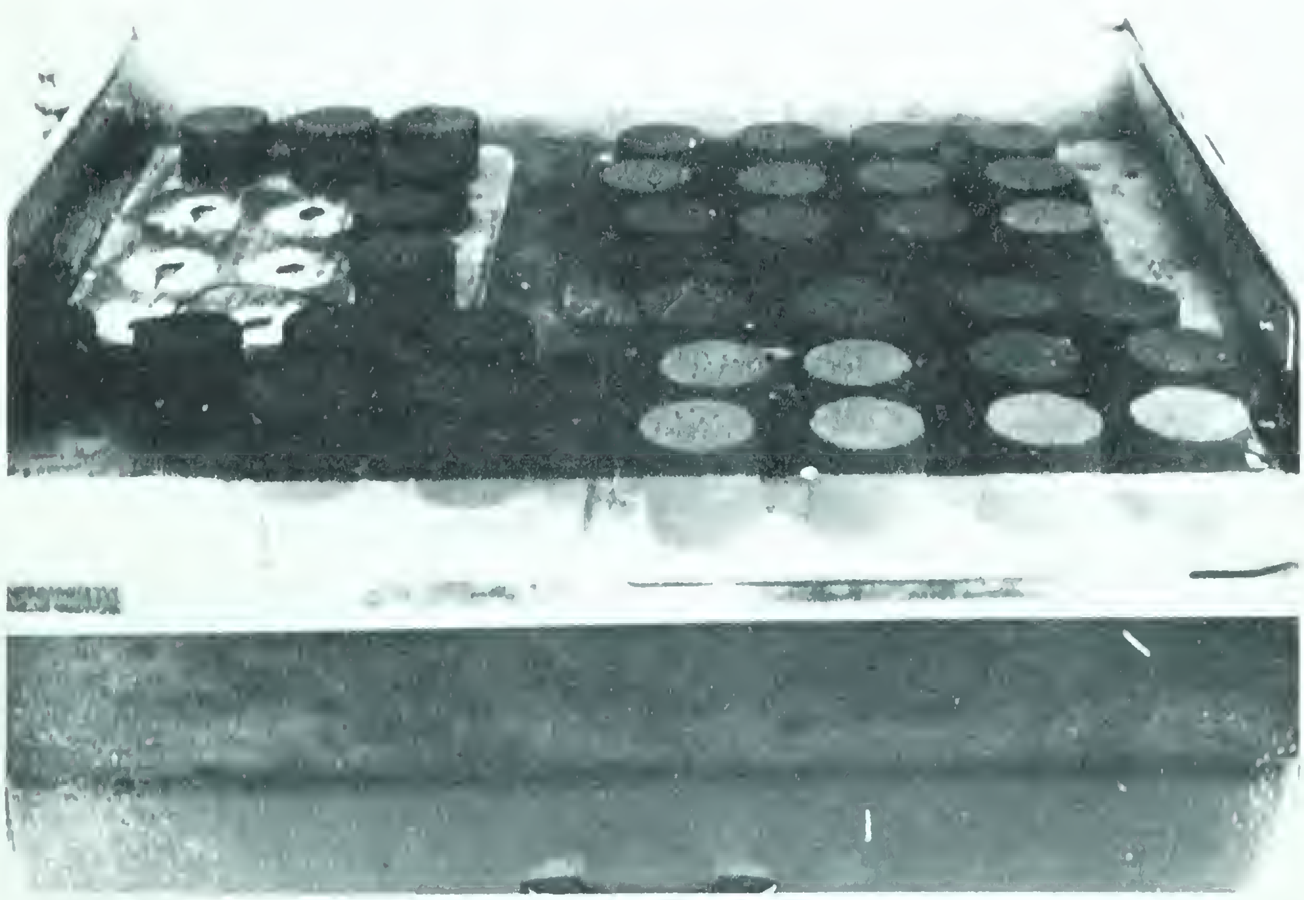
* Volatile content in this report refers to the evaporable water and diluent in the specimens.



VIEW OF PUGMILL SHOWING
TWIN SHAFTS AND BOTTOM DUMPING ARRANGEMENT



SOME OF THE IMMERSION TEST SAMPLES

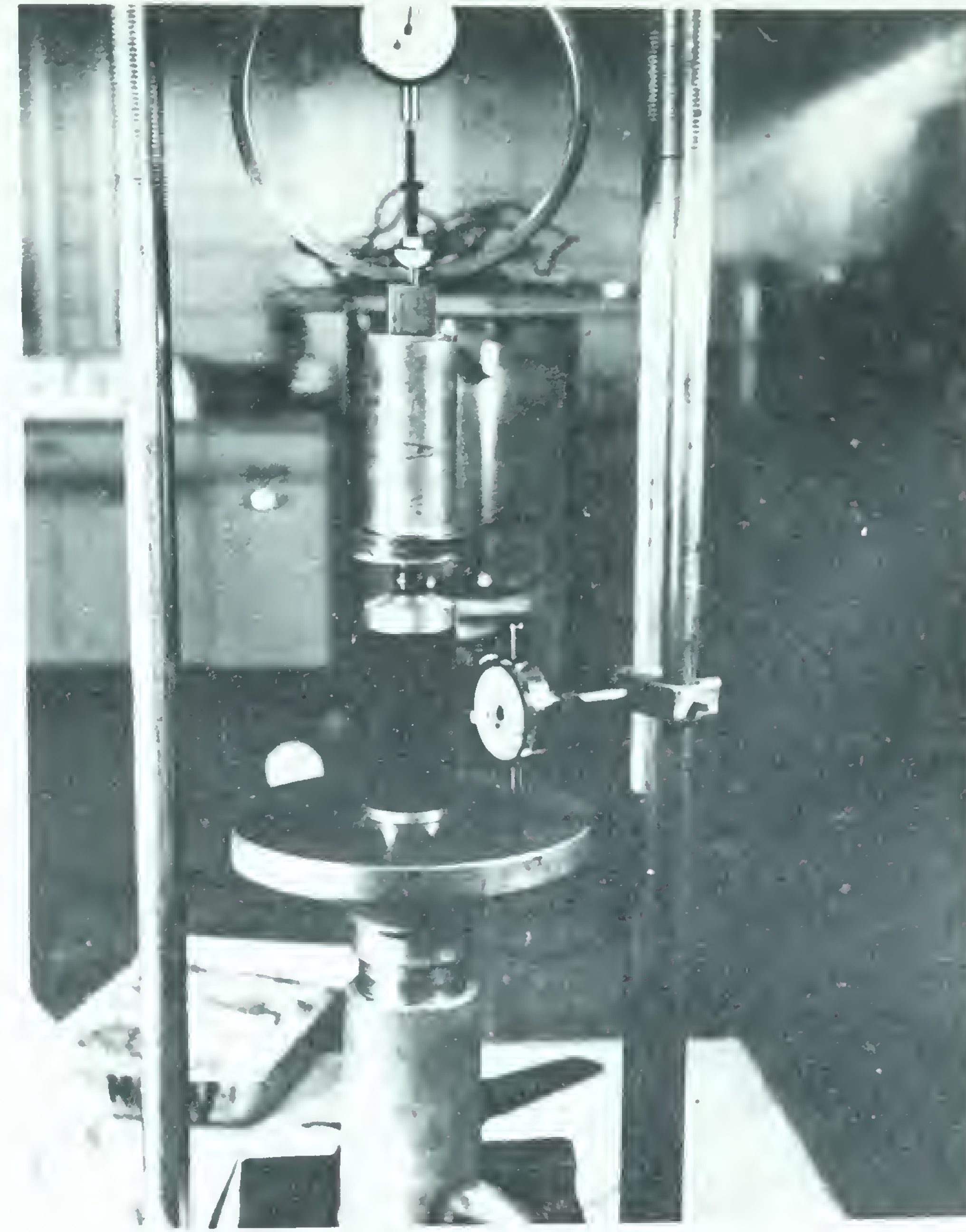
PLATE II

specimens after 6 of the 12 had been molded. The method of molding the samples is shown in the photograph on the left of Plate III. The mold size was 2 inches inside diameter by 6 inches high. A steel plunger 2 inches in diameter and 2 inches high was set on the base plate and the 3/4 inch high spacer collar placed around it as shown. The mold was then placed over the bottom plunger and the mixture added. Ten blows of the 5.5 lb rammer were applied to each of the four layers. Each layer was scarified lightly with a few strokes of a screw driver blade before more mixture for the next layer was added. After the second layer had been compacted, the collar supporting the mold from the base plate was removed and the last two layers compacted. Removal of the collar prior to compacting the second layer caused the mold to slide down on the bottom plunger to the base plate, precluding the molding of a specimen four inches in length. After compaction of the four layers had been completed, the mold with compacted mix and bottom plunger was transferred to a hydraulic press. The mold was forced down flush with the base of the bottom plunger and the extruded portion of sample trimmed flush with the top of the mold. The trimmed specimen was then extruded from the mold, weighed, and placed in an oven for curing at 110^{O}F.

Unconfined Compression Testing

The unconfined compression testing of samples was done by the use of a Soiltest Model CN-472 hand operated unconfined compression apparatus shown being used in the photograph on the right of Plate III. Samples were placed in the apparatus as shown in the photograph and the load applied at a constant strain rate of 0.03 inches per minute

METHOD OF MOLDING THE SPECIMENS



UNCONFINED COMPRESSION TEST

PLATE III

with the hand crank by constant checking of a timer. As the samples were all approximately 4 inches high this provided a strain rate of about 0.75 percent per minute. Knowles (1962) in working with 2 inch diameter by 5 inch high specimens used a strain rate of 0.9 percent per minute; Jones (1962) using 2 inch by 2 inch cylindrical specimens employed a 1.5 percent per minute strain rate whereas Rice (1949) used a strain rate of 0.53% per minute in his work on 2 inch high specimens. The strain rate of 0.03 inches per minute was used because of its convenience in controlling the strain manually with the apparatus employed.

The load applied to the specimens was measured by means of a proving ring having a capacity of 600 pounds. Failure load was taken as occurring at the maximum load dial reading. Sample data and calculation sheets are included in Appendices Band C.

Water Immersion Testing

After curing the desired period, samples that were to be immersed were weighed along with the three samples that were to be tested in a dry condition. The immersion samples were placed on wooden trays in which holes had been drilled to assure water access from all sides. The trays were set at the bottom of five inch deep metal tanks which had been sufficiently filled with tap water to completely immerse the samples. The water level was maintained about one quarter inch above the top of the specimens, by adding fresh tap water when required. The temperature of the water varied from a low of $65^{\circ}F$ fresh from the tap to a high of $70^{\circ}F$ at a room temperature of $70^{\circ}F$. The samples were immersed for periods of 7, 14 and 21 days. If twelve samples

had been cured for the particular test series, then three samples were subjected to unconfined compression testing immediately after curing, three more after 7 days immersion, three after 14 days immersion and the last three after 21 days immersion. The immersed samples were weighed in a surface damp-dried condition approximately daily to provide data on their water absorption characteristics. A photograph of one of the tanks showing some of the samples is in Plate II. A sample data sheet is included in Appendix B.

Analysis of Data

Voids Calculations: In order to reduce the number of computations a value of 205.5 cubic centimeters was used for the volume of the specimens with the exception of one test series of six samples in which one sample was less than $3\frac{1}{2}$ inches in length. In the latter case the individual sample volumes were calculated and averaged for the voids determinations. The value of 205.5 cubic centimeters was the average of 100 cured samples. Maximum deviation from this volume was 5.5 cubic centimeters. However as many of the immersed samples became particularly soft and difficult to measure accurately the average value used is considered to be more realistic of actual volumes of the samples.

The weights of all the materials added for each batch were tabulated and the actual percentage of MC3 added was determined in each case. Then assuming 79 percent residue from the MC3 (the average value from 9 samples after 14 days at 110°C) the percentage of each total mix that was residual asphalt was determined.

The molded weights of each group of samples were averaged and the

oven-dry weight of sand plus the weight of residual asphalt determined from the volatile content. Using the percentage of the total mix that was residual asphalt, the weight of residual asphalt was determined from the average molded weight of the specimens. The dry weight of sand was the weight of the sand and residual asphalt minus the weight of residual asphalt. The volume of sand was calculated using the previously determined specific gravity of 2.66. The volume of voids in the aggregate was taken as the difference between the total sample volume of 205.5 cubic centimeters and the volume of the sand. The percent of voids in the aggregate* of the sample was the volume of the voids divided by the volume of the sample, expressed as a percentage.

The volume of water in a specimen at any time was the total weight of the specimen minus the weight of dry sand plus residual asphalt. Void calculations were made for each group of samples to reduce computations. This means that for a group of nine samples being subjected to 7, 14 and 21 days of water immersion, the voids calculations for the first 7 days were based on the average of nine specimen weights the next 7 days based on six specimens, and the last 7 days based on three specimens. A sample calculation is included in Appendix C.

Unconfined Compressive Strength: Failure loads for the unconfined compression test samples were taken from calibration curves prepared for the 600 pound proving ring. An area correction table was prepared and the area determined from the initial diameter and unit strain at failure. This assumed deformation at constant volume,

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* Voids in the aggregate is a phrase frequently used in bituminous mixture terminology and may be considered to have a similar meaning as the term porosity in soil mechanics.

that is:

$$Ac = \frac{Ao}{1 - e}$$

where,

Ac = area at failure load

Ao = initial area

e = unit strain

A sample calculation is included in Appendix C.

CHAPTER V

DISCUSSION OF TEST RESULTS

Preliminary Testing

Figure 1 shows the relationship between the unconfined compressive strength of samples and curing time at 110°F. Each point on the curve is the average of three test samples. As an apparent maximum strength is reached after 120 hours curing, it was decided that this would be the longest curing period used in the main testing programme. Two other curing periods, 24 hours and 72 hours, were selected in order to study the effects of shorter curing periods on durability of the compacted mixtures.

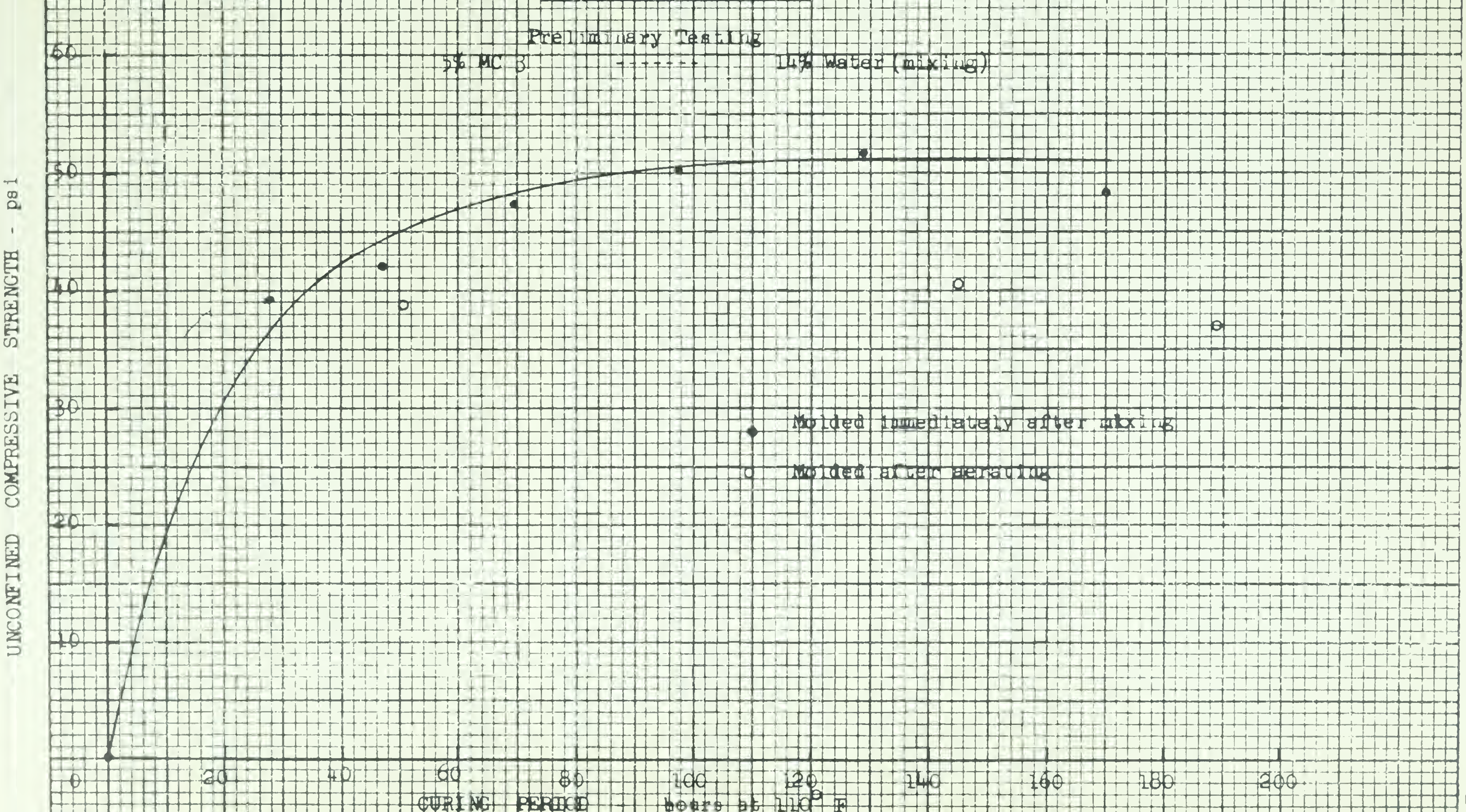
Although the volatile content was not noticeably decreased by drying the mix in the bag, the unconfined compressive strengths of the samples which were molded from this slightly aerated mix, were markedly reduced. The three isolated points in Figure 1 show this reduction. It was therefore decided that a part of the investigation would include a study on aerated mixtures.

A plot of residual asphalt content versus time in an oven at 110°C was prepared from tests of nine samples of the cutback asphalt. It was determined that 15 percent of the asphalt evaporated as volatiles within two days. After 14 days at 110°C approximately 21 percent of the asphalt had evaporated as volatile leaving a residual of 79 percent. This compared with the manufacturers data of 80.0 percent residual based on the distillation test for cutback asphalt as outlined in ASTM Method of Test D402-55.

Figure 1

VARIATION IN UNCONFINED COMPRESSIVE STRENGTH

WITH CURING PERIOD



Main Testing Programme

Effect of Molding Water Content on the Unconfined Compressive Strength of Cured Samples: Plots of the unconfined compressive strengths of samples tested immediately after curing for various times were drawn against molding water contents and are shown in Figure 2. Regardless of the curing time allowed or the quantity of cutback asphalt in the mixture, maximum compressive strengths of the cured samples occurred at a molding water content of about 14 percent. There appeared to be a tendency towards a slightly lower molding water content for maximum strength with higher percentages of cutback but a definate trend is not established. The broken lines in Figures 2a and 2c show the relationship between the cured unconfined compressive strength of samples compacted at differing molding water contents following aeration. Drying back the mixture before molding, reduced the compressive strength of the cured specimens.

Effect of Cutback Asphalt Content During Molding on the Cured Unconfined Compressive Strength: Increasing the cutback asphalt content in the mixture reduced the unconfined compressive strength of samples tested immediately after curing. The same trend occurred in all mixes regardless of curing period, molding water content, or whether they were aerated before molding. An increase of cutback from 1 to 4 percent in the mix reduced the compressive strength of the cured samples by more than 60 percent in some cases. The reduction in strength with increased cutback content is shown in Figure 3.

Figure 2

EFFECT OF MOLDING WATER CONTENT ON UNCONFINED COMPRESSIVE STRENGTH

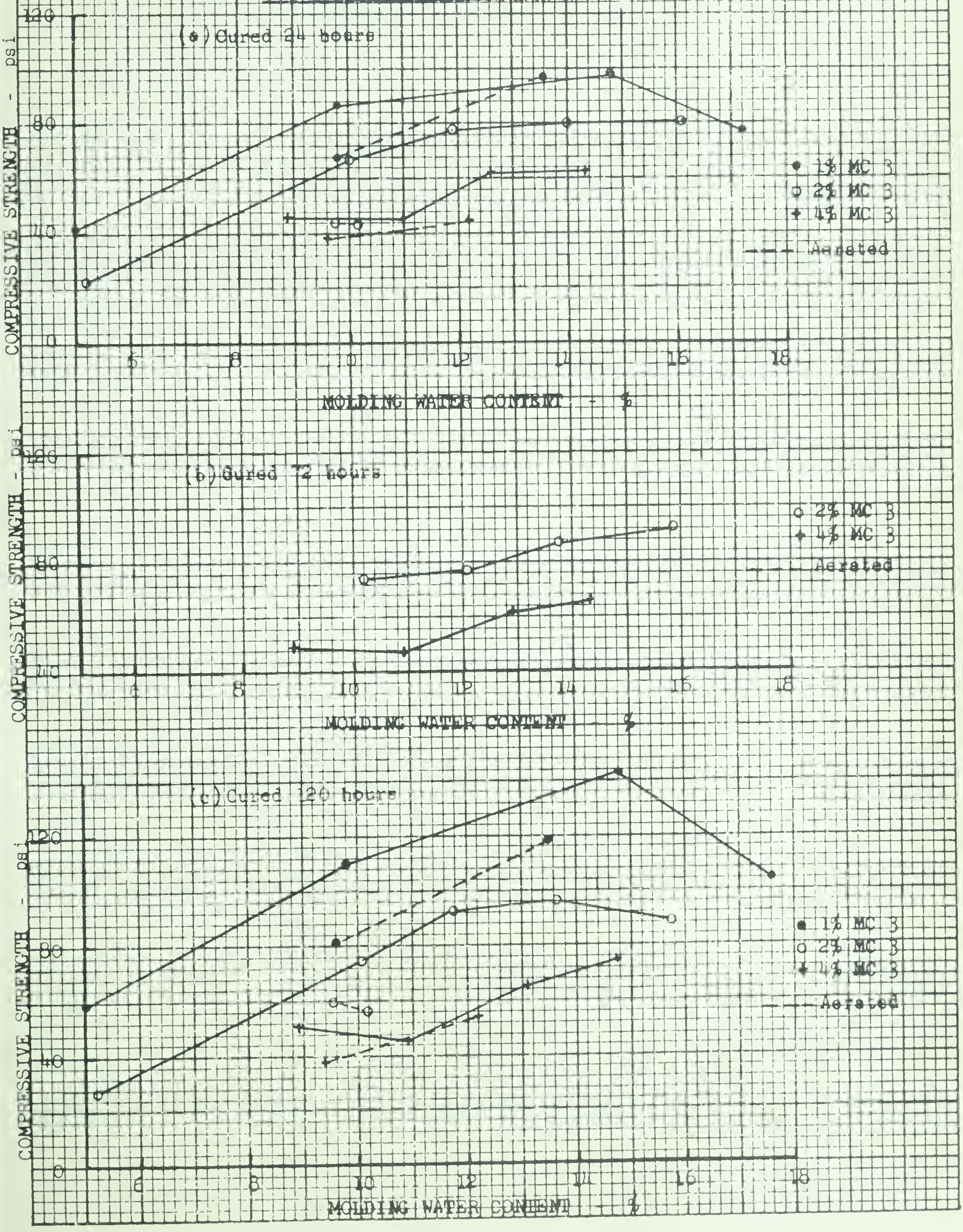
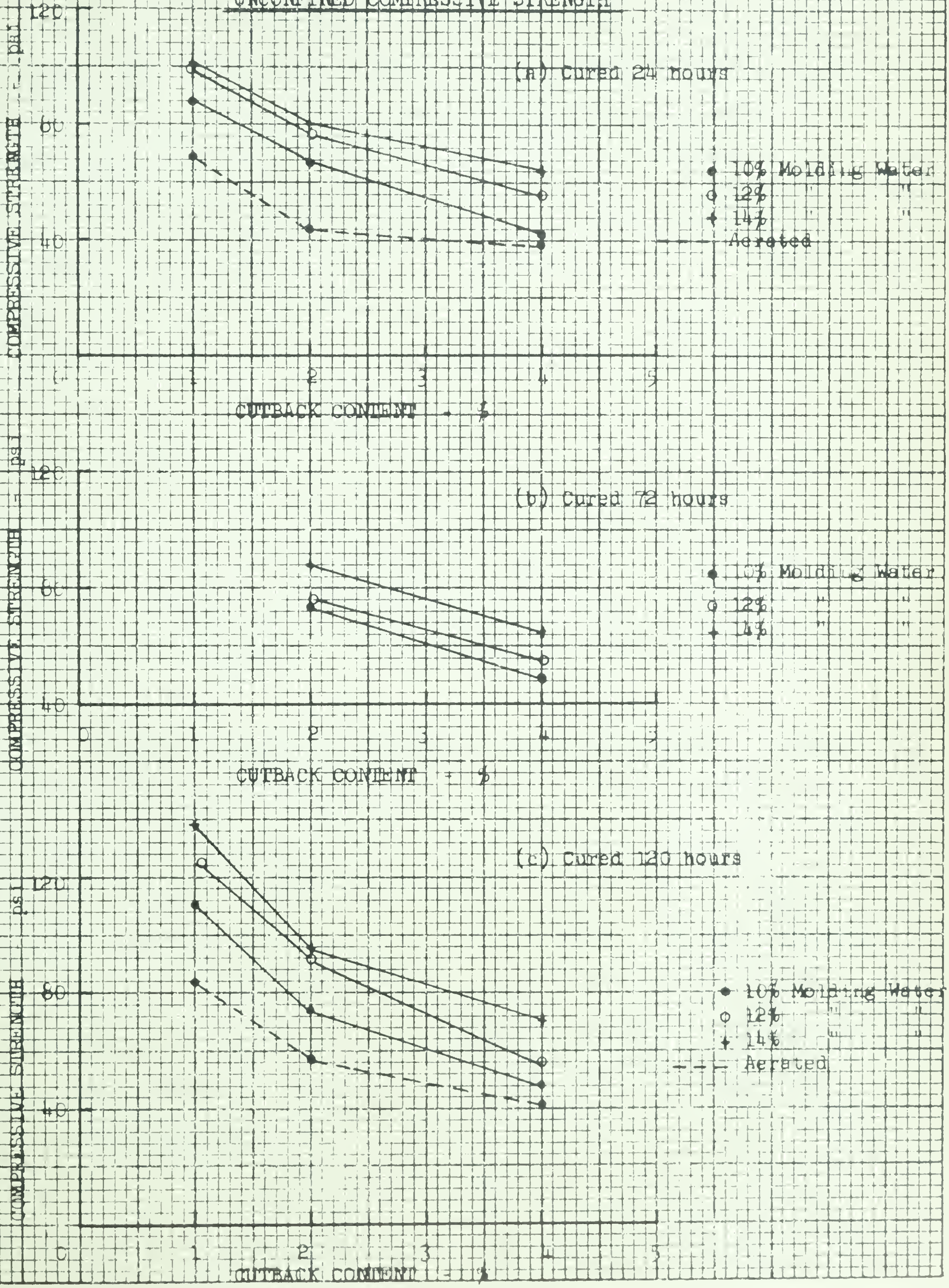


Figure 3

EFFECT OF CUTBACK CONTENT ON UNCONFINED COMPRESSIVE STRENGTH



Effect of Curing Period on the Unconfined Compressive Strength of Cured Samples: Curing the molded specimens for longer periods of time increased the unconfined compressive strength in almost every case as shown in Figures 4,5 and 6. Curing appeared to be most beneficial to mixtures containing lower asphalt contents. Increasing the curing period from 24 hours to 120 hours caused a maximum compressive strength increase of 46 percent in the mixture containing one percent cutback whereas a similar increase in curing period contributed to a strength increase of only 19 percent in the mixture containing four percent asphalt. As postulated by Jones (1962) there may be two reasons for this. Evaporation of pore water is more difficult at higher asphalt contents so that less tension is created in the pore water with resulting lower strength. Also indications are that the asphalt acts partially as a lubricant rather than a cement after curing only five days at 110°F. It can be seen from the figures that curing was also beneficial to the samples which were molded from the aerated mixtures.

Variation of Percent Air Voids in the Molded Samples: Figure 7 shows that nearly a straight line relationship exists between air voids in the molded samples with both water content and cutback asphalt content. Increasing the amount of either water or cutback asphalt will reduce the air voids in the compacted samples. Obviously a minimum air voids content will be reached on the wet side of the optimum molding water content for maximum dry density. The same relationship holds for the aerated mixtures as for those molded immediately after mixing.

Figure 4

EFFECT OF CURING ON

UNCONFINED COMPRESSIVE STRENGTH

1% Cutback

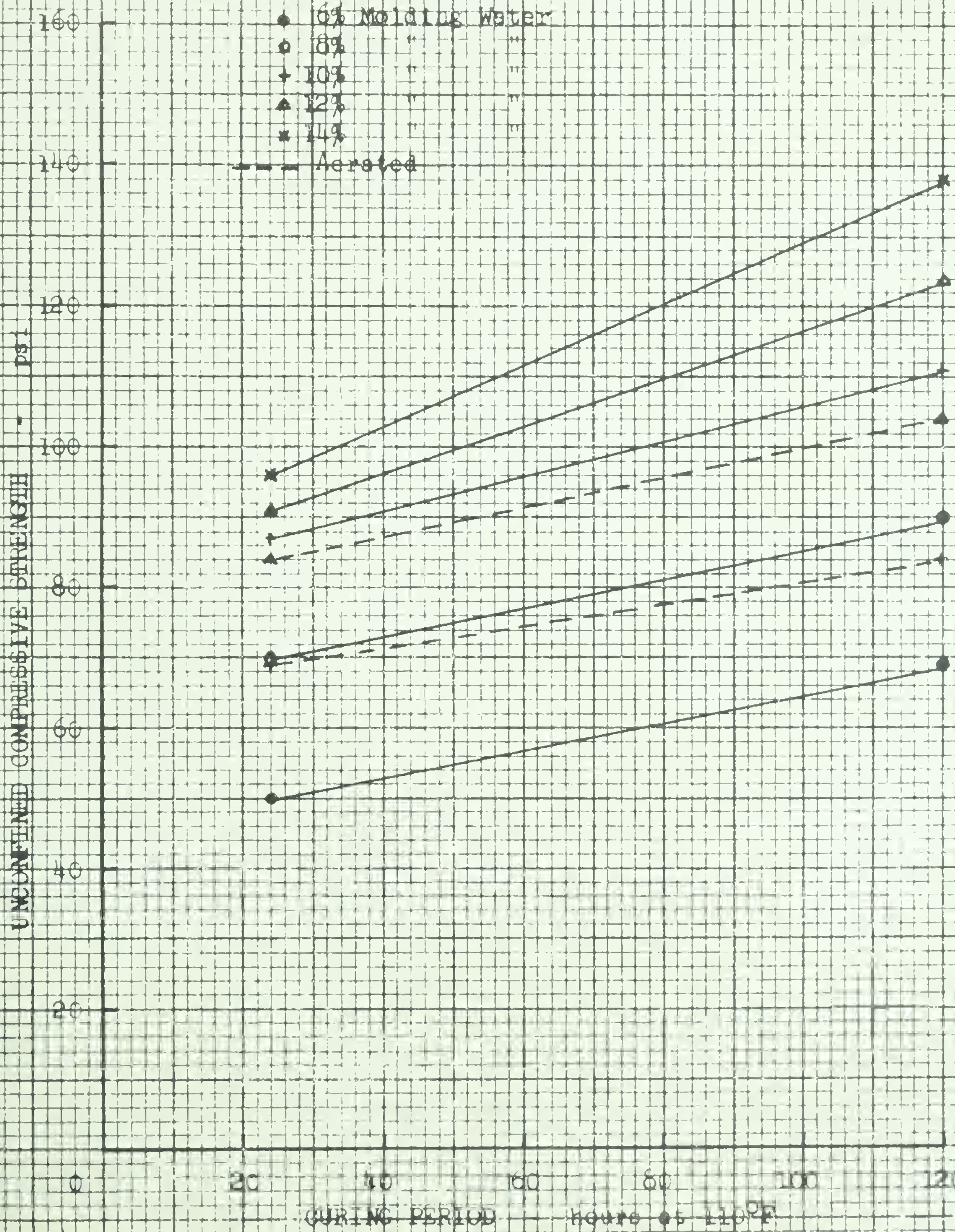


Figure 5

EFFECT OF CURING ON

UNCONFINED COMPRESSIVE STRENGTH

2% Cutback

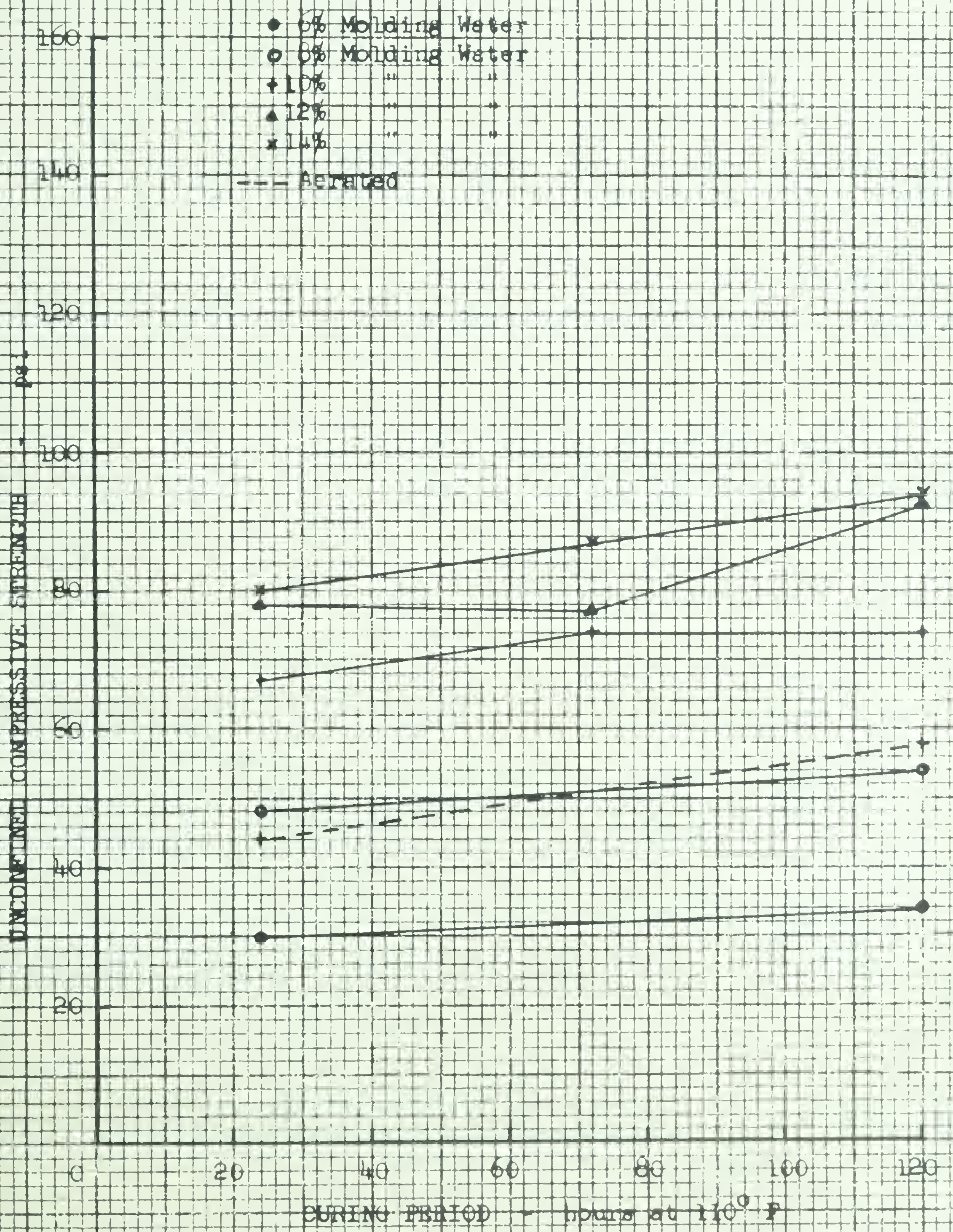


Figure 6

EFFECT OF CURING ON

UNCONFINED COMPRESSIVE STRENGTH

4% Cutback

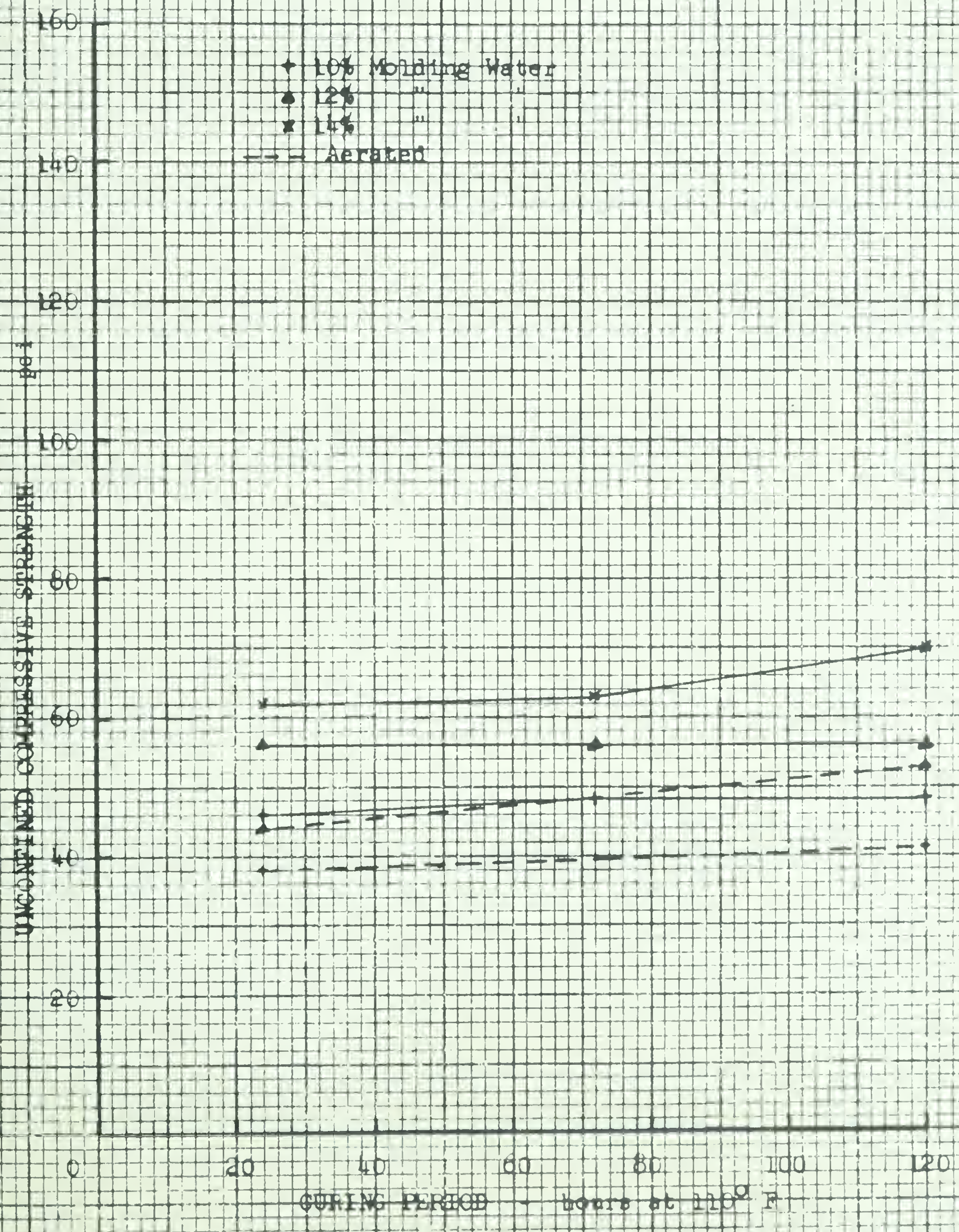
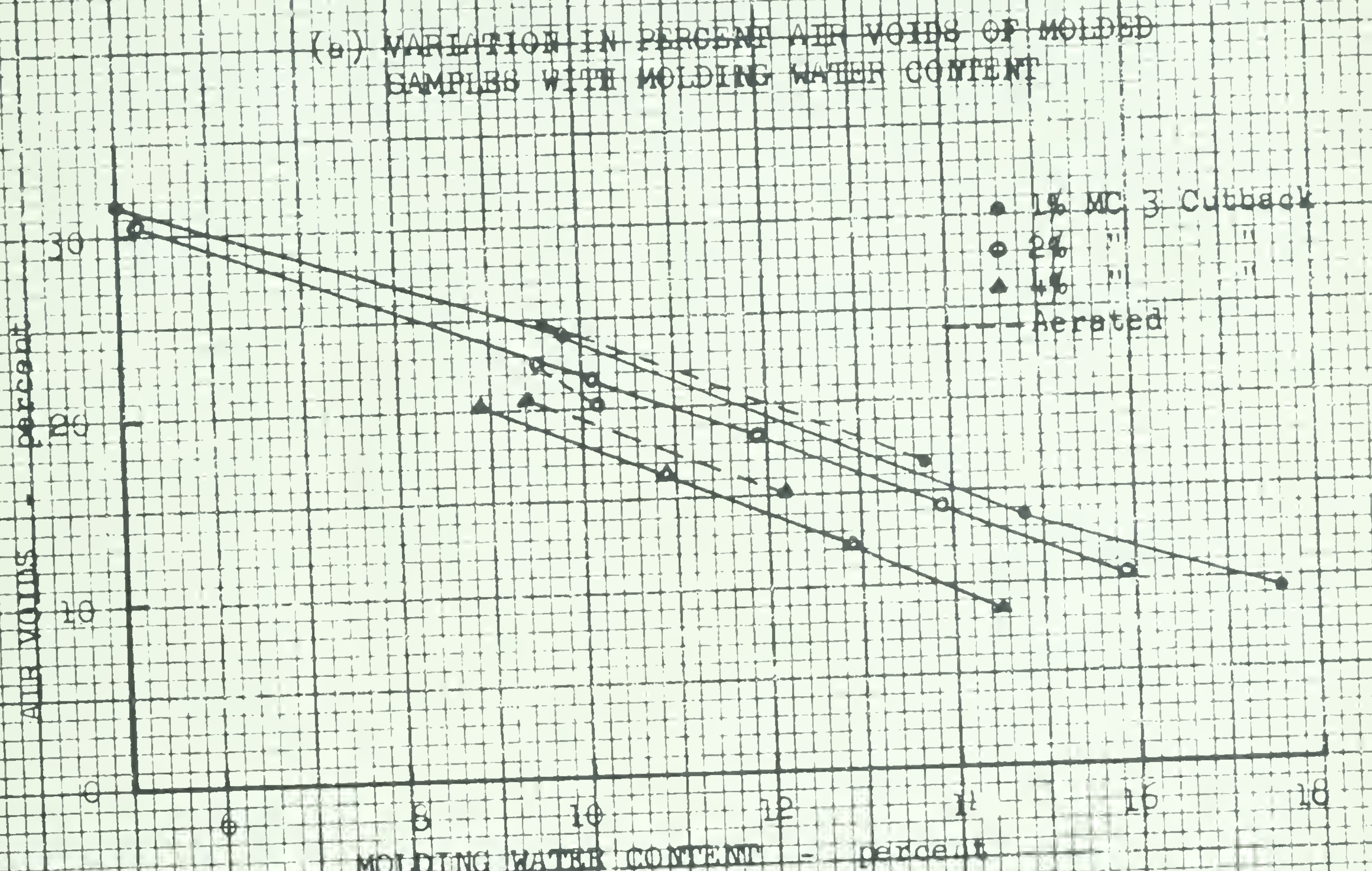


Figure 7

AIR VOIDS IN THE MOLDED SAMPLES



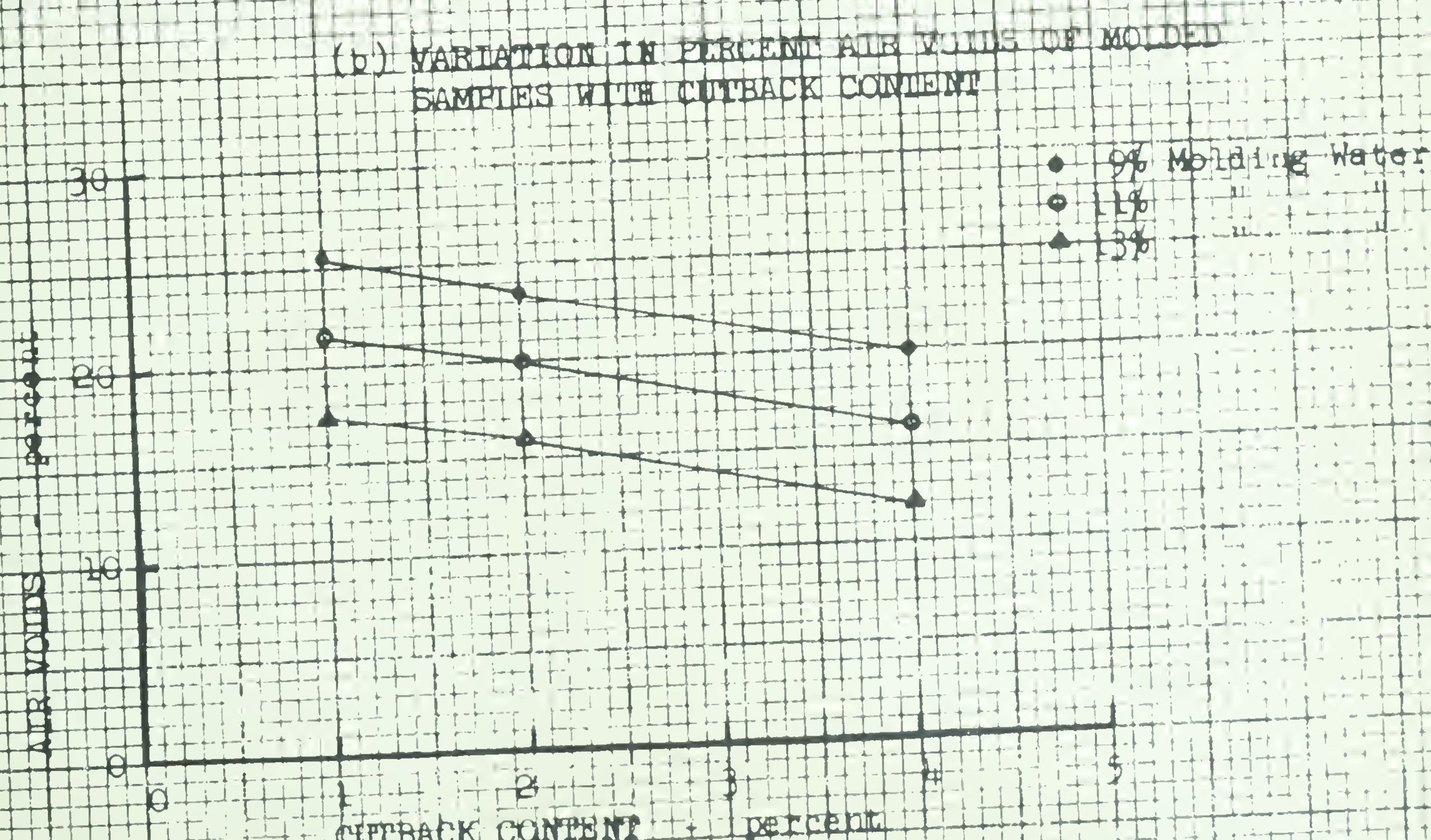
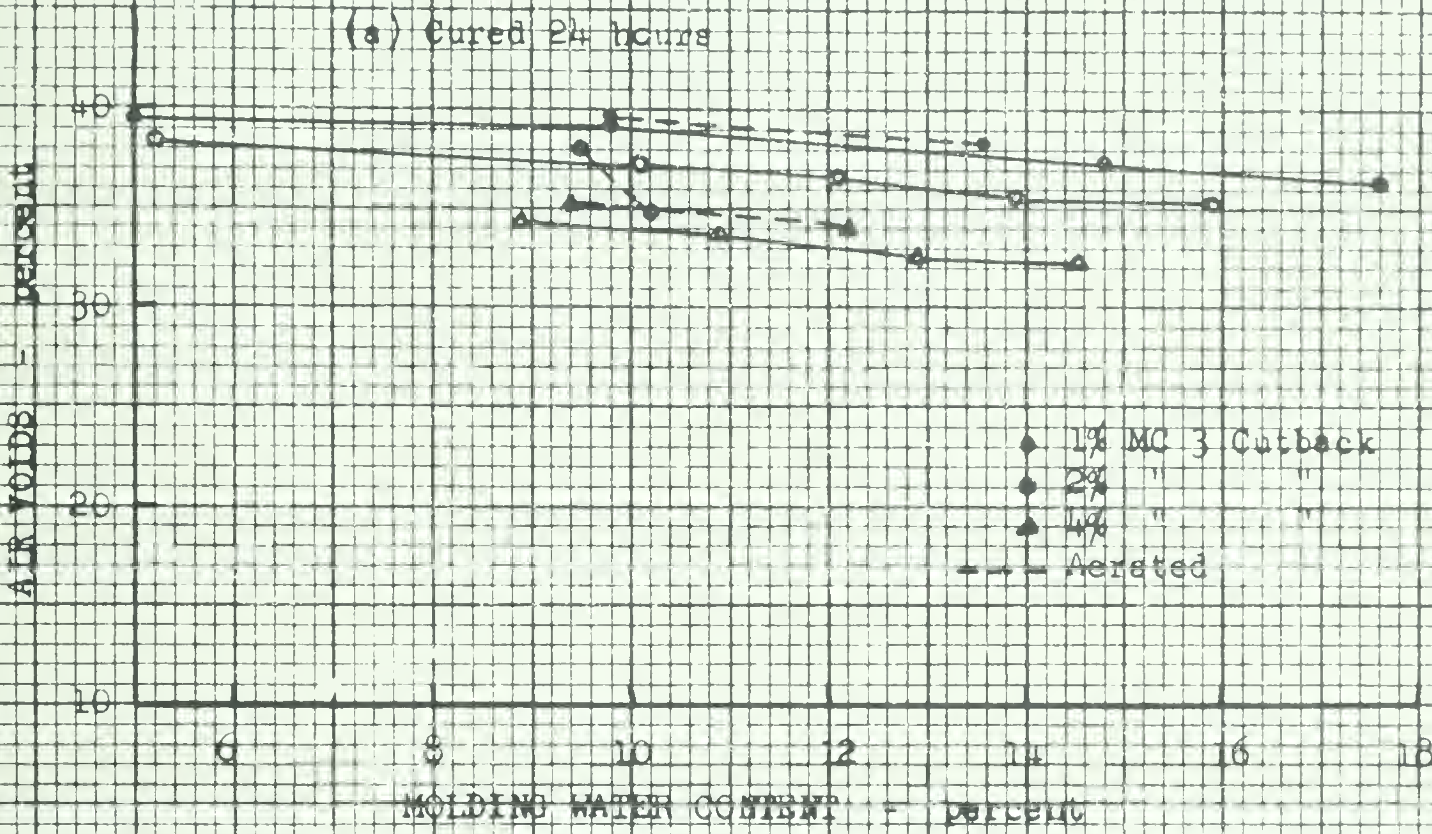


Figure 8

VARIATION IN AIR VOIDS OF CURED SAMPLES

WITH MOLDING WATER CONTENT



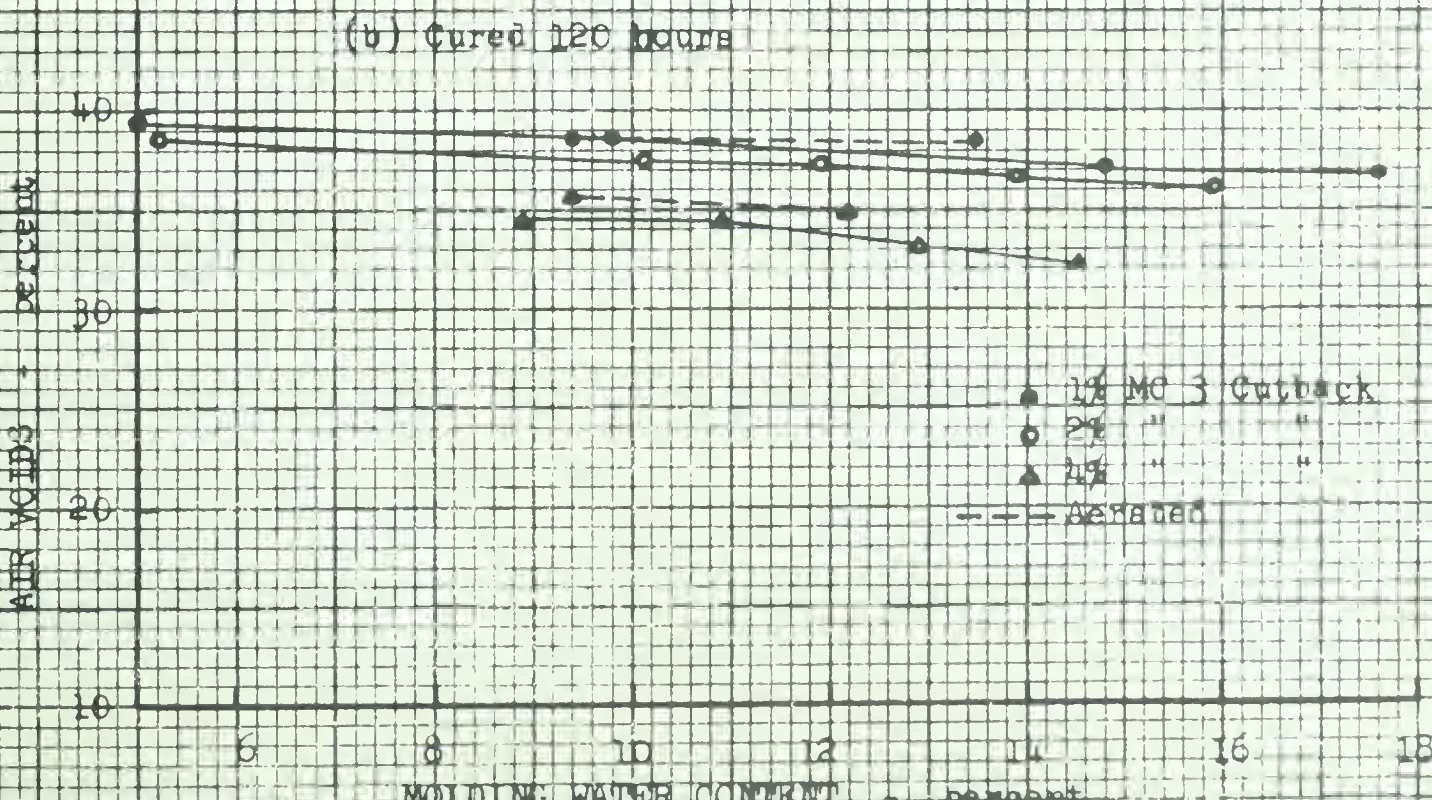


Figure 9

VARIATION IN AIR VOIDS OF CURED SAMPLES

WITH MOLDING CUTBACK CONTENT

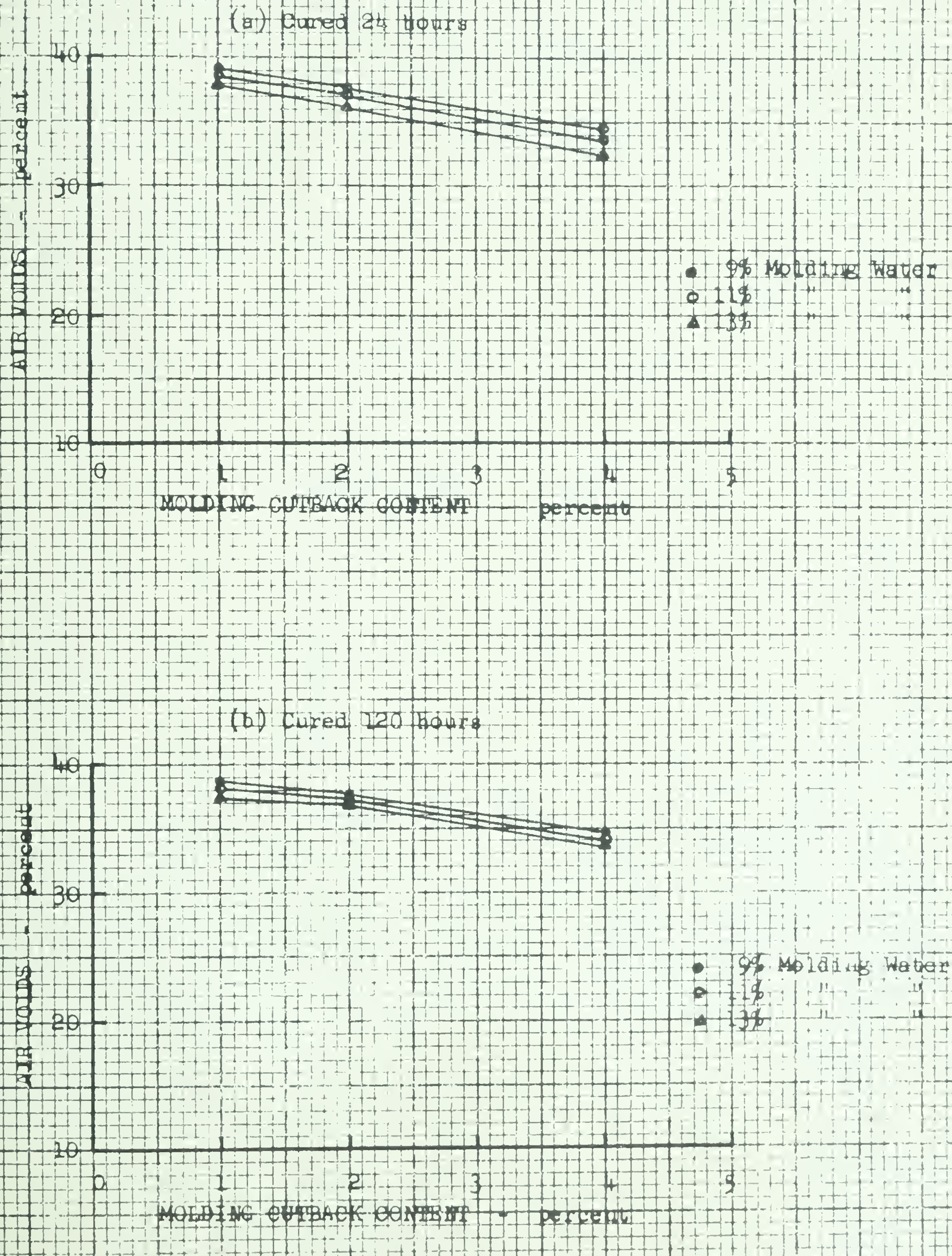
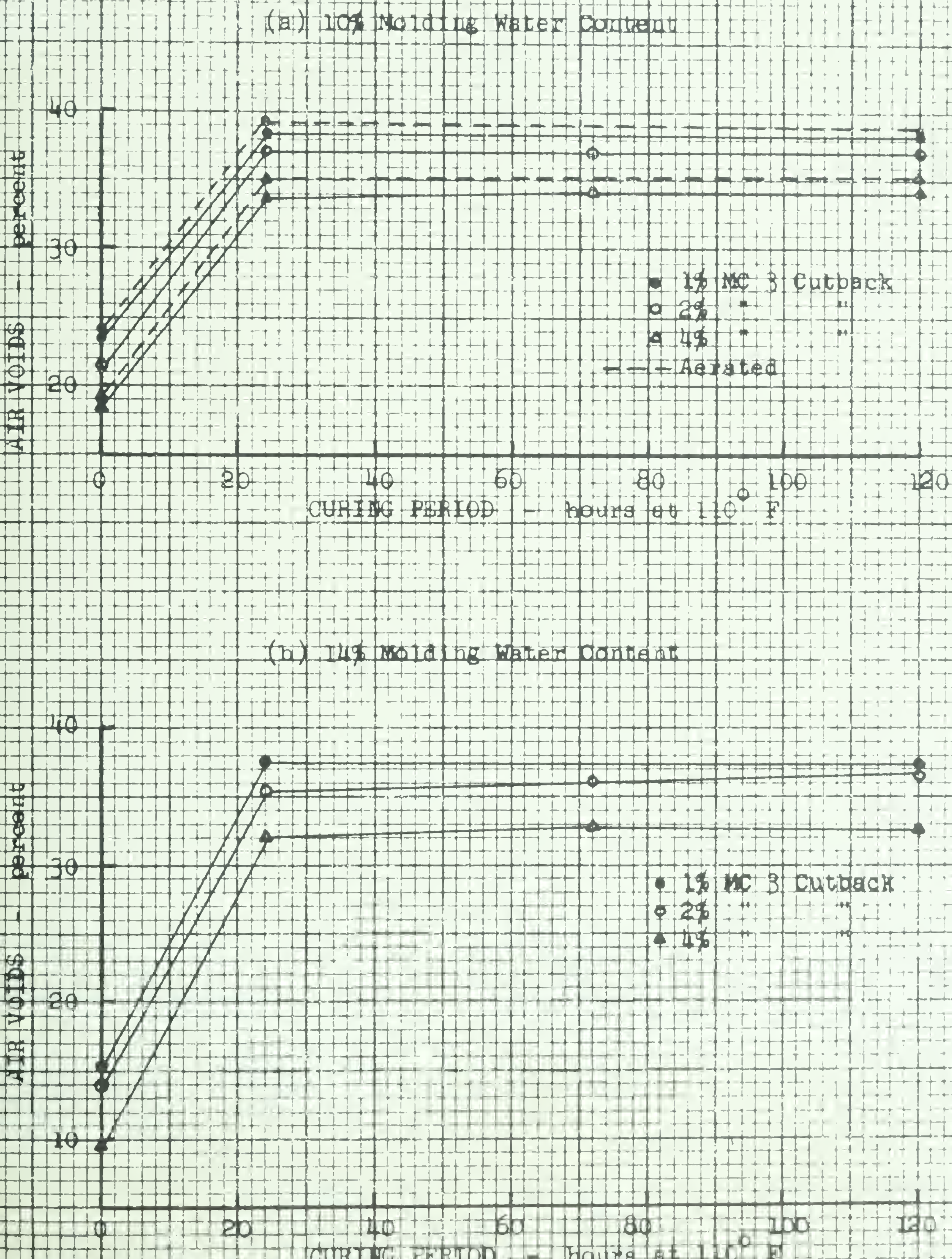


Figure 10

EFFECT OF CURING ON AIR VOIDS CONTENT



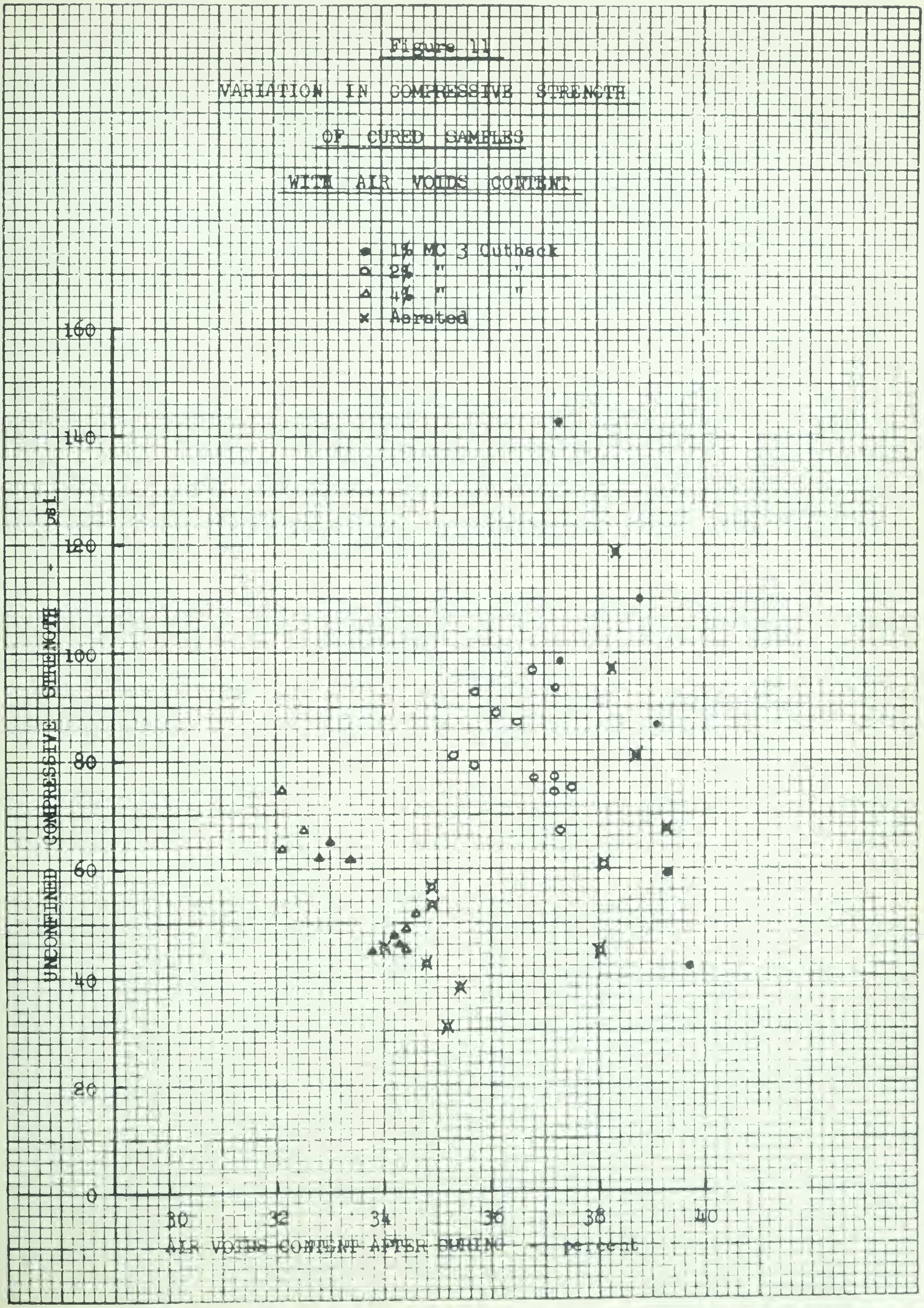


Figure 11
VARIATION IN COMPRESSIVE STRENGTH
OF CURED SAMPLES
WITH AIR VOIDS CONTENT
● 1% MC 3 Cutback
○ 2% " "
△ 4% " "
✕ Aerated
UNCONFINED COMPRESSIVE STRENGTH - psi
0
20
40
60
80
100
120
140
160
30
32
34
36
38
40
AIR VOIDS CONTENT AFTER CURING - percent

Figure 12

VARIATION IN DRY DENSITY OF MOLDED SAMPLES WITH MOLDING WATER CONTENT

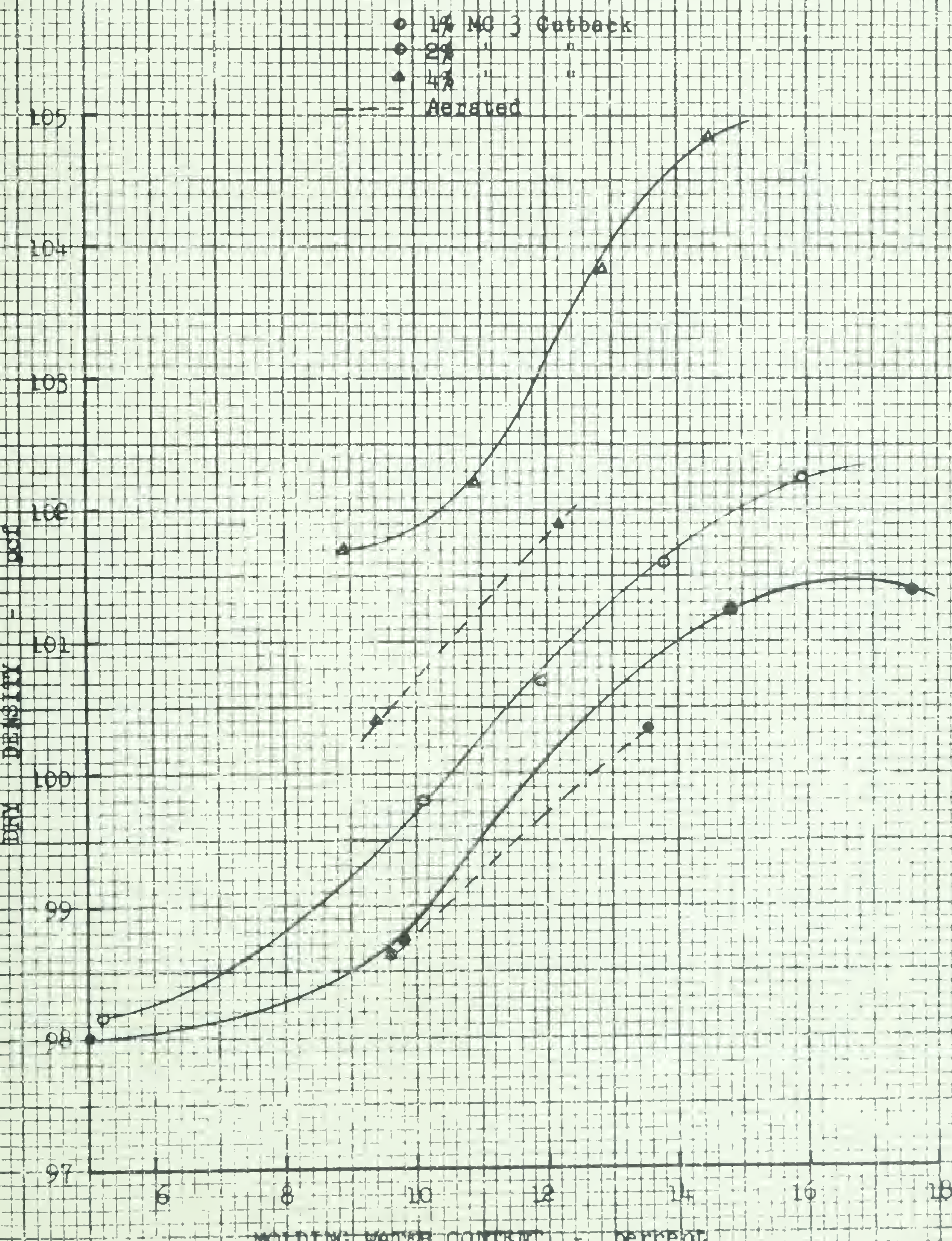
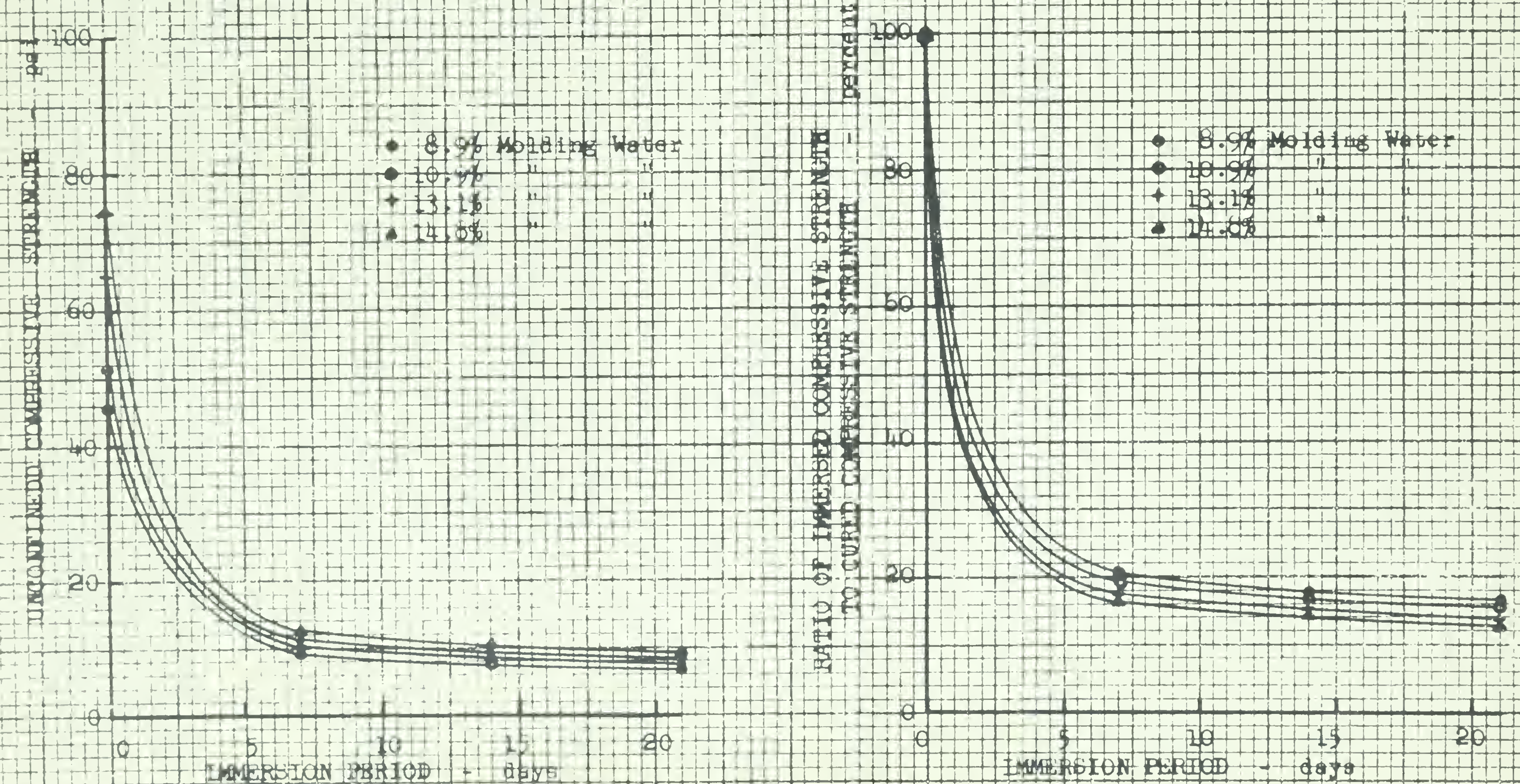


Figure 13

EFFECT OF WATER IMMERSION

ON COMPRESSIVE STRENGTH

4 PERCENT CUTBACK ---------- CURED 120 HOURS



Effect of Curing On Percent Air Voids: Figures 8 and 9 show the variation in air voids of cured samples with molding water and cutback content, while Figure 10 shows the effect of curing on the air voids content. Curing for 24 hours increased the air voids in the molded samples more than three fold in some cases. Curing for periods longer than 24 hours increased the air voids content only slightly or not at all. This conflicts with the report of Herrin (1958) who found a fairly continuous increase in air voids content with curing up to 14 days. However the soil used by Herrin was more densely graded than the fine sand used in this investigation, and the method of compaction was different so that no direct comparison can really be made. Herrins study also showed that the water in the compacted samples evaporated at a much faster rate than did the diluent.

Volatile content determinations were made on all cured samples after testing by drying in an oven for two days at 110^{o}C. Based on the previously determined residual asphalt content of 85 percent after two days at 110^{o}C, the amount of water in the specimens after curing was calculated. It was found that after curing only 24 hours the maximum amount of water still in the specimens was less than 0.3 percent of the oven dried weight of sand. It would appear therefore that curing beyond the 24 hour period allows continued evaporation of the diluent whereas practically all of the water is driven off within 24 hours.

The same relationship between percent air voids in the mix and curing time held for the aerated mixtures.

Relationship Between Percent Air Voids And Unconfined Compressive Strength: As there was very little change in air void content with increased curing time beyond 24 hours, there is no apparent relation-

ship between the unconfined compressive strength and percent air voids after curing as shown in Figure 11. The large increases in compressive strength which result from curing for longer periods are probably directly related to the additional small decrease in the remaining diluent. As no distillations were conducted in this study this possible relationship can only be assumed to exist.

Effect of Aerating Mixtures Before Molding on the Unconfined Compressive Strength: Aerating the mixture caused a reduction in the unconfined compressive strength of the cured samples when compared with samples molded immediately after mixing and at the same molding water contents. The air voids content of the molded and cured samples which had been made from dried back mixtures was higher than for samples that had been molded without aeration. Apparently, drying the mixture before molding permits some of the diluent to evaporate thus creating a mixture more resistant to compaction and resulting in higher air voids content and lower dry density. Refer to Figures 2 and 7.

Relationship Between Dry Density and Molding Water Content: The relationship between dry density and molding water content is shown in Figure 12. Maximum dry density appears to occur at molding water contents between 16 and 17 percent for the one percent cutback, while for the higher cutback contents the maximum densities were not reached. Aerating the mixtures before molding the samples reduced the dry density.

Effect of Water Immersion on Unconfined Compressive Strength: Figure 13 shows the decrease in compressive strength with water immersion. Although only the results for samples containing four percent cutback and cured 120 hours are shown to avoid confusion, similar results were obtained with samples containing one and two percent cut-

back and for curing periods of 2 4 and 72 hours as shown in Table IV. All samples subjected to water immersion showed a large loss in compressive strength after seven days. Maximum strength loss after seven days immersion was 93 percent of cured strength. The further loss in strength for periods longer than seven days immersion was much less, an average value being five percent of the initial strength for an additional 14 days. High compressive strengths of the cured samples did not produce a proportionately higher strength in similar samples after water immersion. Therefore compressive strength in the cured or so-called dry state is no criterion of the durability of the compacted sample. The highest compressive strength of the samples tested in the cured condition was 143 pounds per square inch attained by a mixture of 1 percent cutback and 14.8 percent water and cured for 120 hours. After seven days water immersion the strength of samples from this mixture had dropped to 9.7 pounds per square inch, a decrease of 93 percent. Conversely, the mixture containing 4 percent cutback and 8.9 percent molding water produced a relatively low strength of 51 pounds per square inch in the 120 hour cured product but nearly 21 percent of that strength, 10.4 pounds per square inch, remained after seven days water immersion.

Effect of Molding Water and Cutback Content On Compressive Strength After Immersion: Figures 14, 15 and 16 show the relationship between immersed compressive strength and molding water content. There appears to be a trend for higher immersed compressive strengths at higher molding water contents. Figures 17, 18 and 19 show the effect of molding cutback content on immersed compressive strength and are for the most part horizontal with possibly a very slight trend towards

TABLE IV

UNCONFINED COMPRESSIVE STRENGTH OF SAMPLES

BEFORE AND AFTER WATER IMMERSION

MC3 Content	Molding Water Content	Curing Period	Unconfined Compressive Strength						
			After Curing	7 Days Immersion		14 Days Immersion		21 Days Immersion	
%	%	hrs	psi	psi	% of Cured	psi	% of Cured	psi	% of Cured
4	14.35	24	63.1	12.0	19.0	8.85	14.0	8.56	13.6
4	14.35	72	66.3	12.0	18.1	9.36	14.1	8.76	13.2
4	14.75	120	74.3	12.2	16.4	10.5	14.1	9.46	12.7
4	12.6	24	62.0	10.4	16.8	8.31	13.4	8.01	12.9
4	12.9	72	61.6	11.9	19.3	8.81	14.3	8.28	13.4
4	13.1	120	65.0	11.2	17.2	9.52	14.6	8.69	13.4
4	11.0	24	44.5	9.16	20.6	6.61	14.9	6.67	15.0
4	10.9	72	47.6	9.23	19.4	8.38	17.6	7.33	15.4
4	10.9	120	45.9	9.03	19.7	7.84	17.1	7.30	15.9
4	8.9	24	46.2	8.71	18.9	7.17	15.5	6.49	14.0
4	8.9	72	49.0	10.5	21.4	7.92	16.2	7.99	16.3
4	8.9	120	51.4	10.4	20.6	8.70	17.3	8.21	16.3
2	10.0	24	66.8	10.7	16.0	7.61	11.4	6.60	9.9
2	10.1	72	74.5	11.5	15.5	8.57	11.5	7.84	10.5
2	10.1	120	75.1	10.6	14.2	8.14	10.8	8.07	10.7
2	11.9	24	76.7	11.6	15.1	8.64	11.3	7.56	9.9
2	12.0	72	76.9	10.5	13.7	8.09	10.5	7.46	9.7
2	11.8	120	93.4	14.1	15.1	10.4	11.1	10.1	10.8
2	14.0	24	79.7	11.6	14.6	8.33	10.5	7.72	9.7
2	13.9	72	87.6	10.4	11.9	8.26	9.4	8.86	10.1
2	13.7	120	97.1	13.6	14.0	10.2	10.5	9.07	9.3

TABLE IV (continued)

MC3 Content %	Molding Water Content %	Curing Period hrs	Unconfined Compressive Strength: After Curing psi	7 Days psi	Immersion % of Cured	14 Days psi	Immersion % of Cured	21 Days psi	Immersion % of Cured
2	16.1	24	80.5	11.3	14.0	8.96	11.1	8.37	10.4
2	15.8	72	92.9	15.2	16.4	11.6	12.5	11.2	12.1
2	15.8	120	88.8	13.4	15.1	11.2	12.6	9.96	11.2
2	5.2	24	22.7	3.09	13.6				
2	5.2	120	27.8	6.68	24.0				
1	5.0	24	42.1	3.92	9.3				
1	5.0	120	59.1	4.13	7.0				
1	9.8	24	87.4	8.45	9.7				
1	9.8	120	110.	8.37	7.6				
1	14.8	24	98.3	8.43	8.6				
1	14.8	120	143.	9.72	6.8				
1	17.6	24	77.4	9.23	11.9				
1	17.6	120	104.	10.2	9.8				
2	9.5	24	44.3	7.53	17.0				
2	9.5	120	60.4	9.26	15.4				
2	10.2	24	42.3	6.56	15.5				
2	10.2	120	56.4	10.8	19.2				
1	13.6	24	97.5	7.45	7.65		Aerated Mixtures		
1	13.5	120	119.	13.3	11.2				
1	9.8	24	67.6	6.77	10.0				
1	9.4	120	80.9	9.22	11.4				
4	12.2	24	44.8	7.65	17.1				
4	12.2	120	53.8	11.1	20.8				
4	9.4	24	30.8	6.29	20.4				
4	9.4	120	38.0	9.38	24.7				

Figure 14

EFFECT OF MOLDING WATER CONTENT ON COMPRESSIVE STRENGTH AFTER 7 DAYS IMMERSION

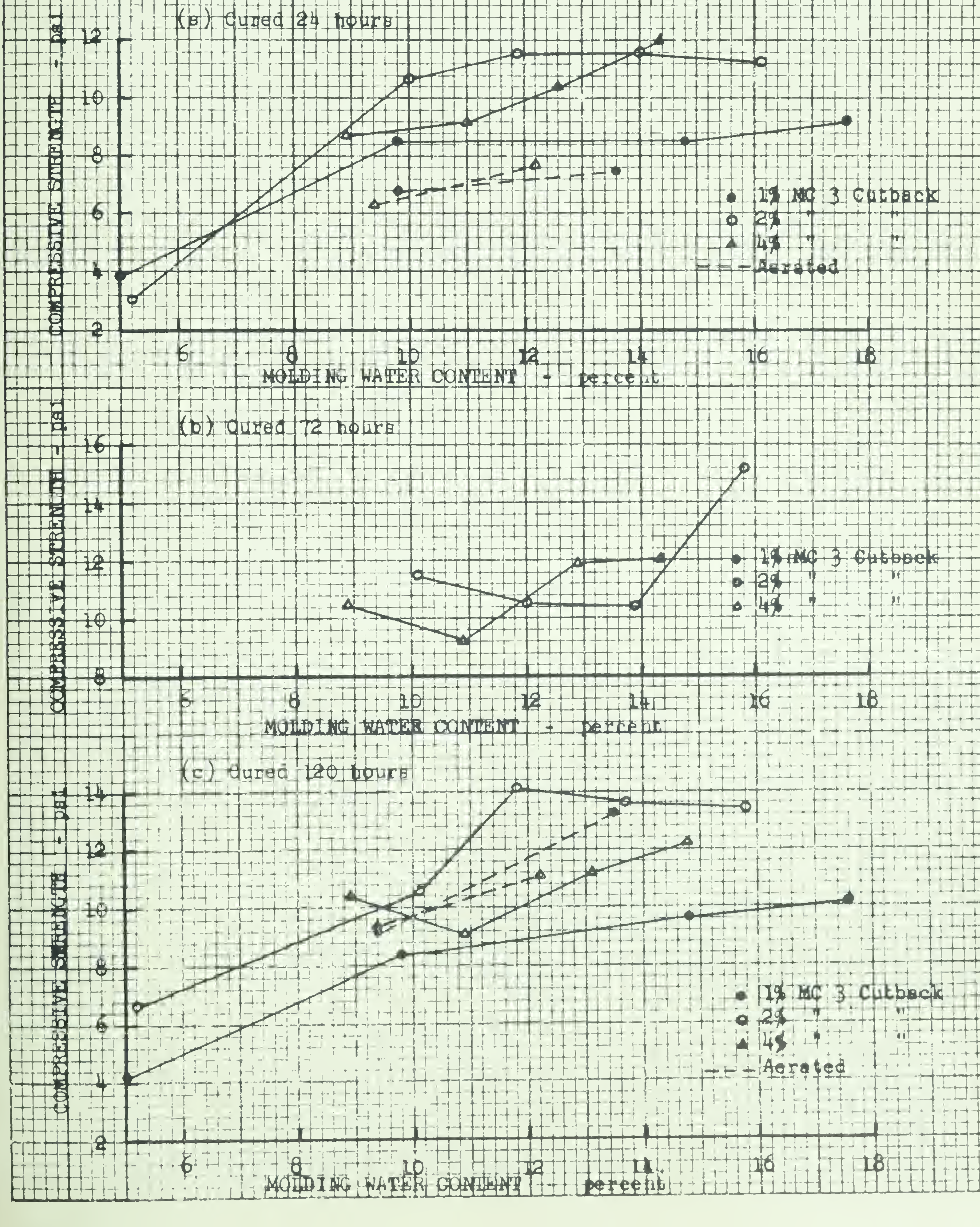


Figure 15

EFFECT OF MOLDING WATER CONTENT ON COMPRESSIVE STRENGTH

AFTER 14 DAYS IMMERSION

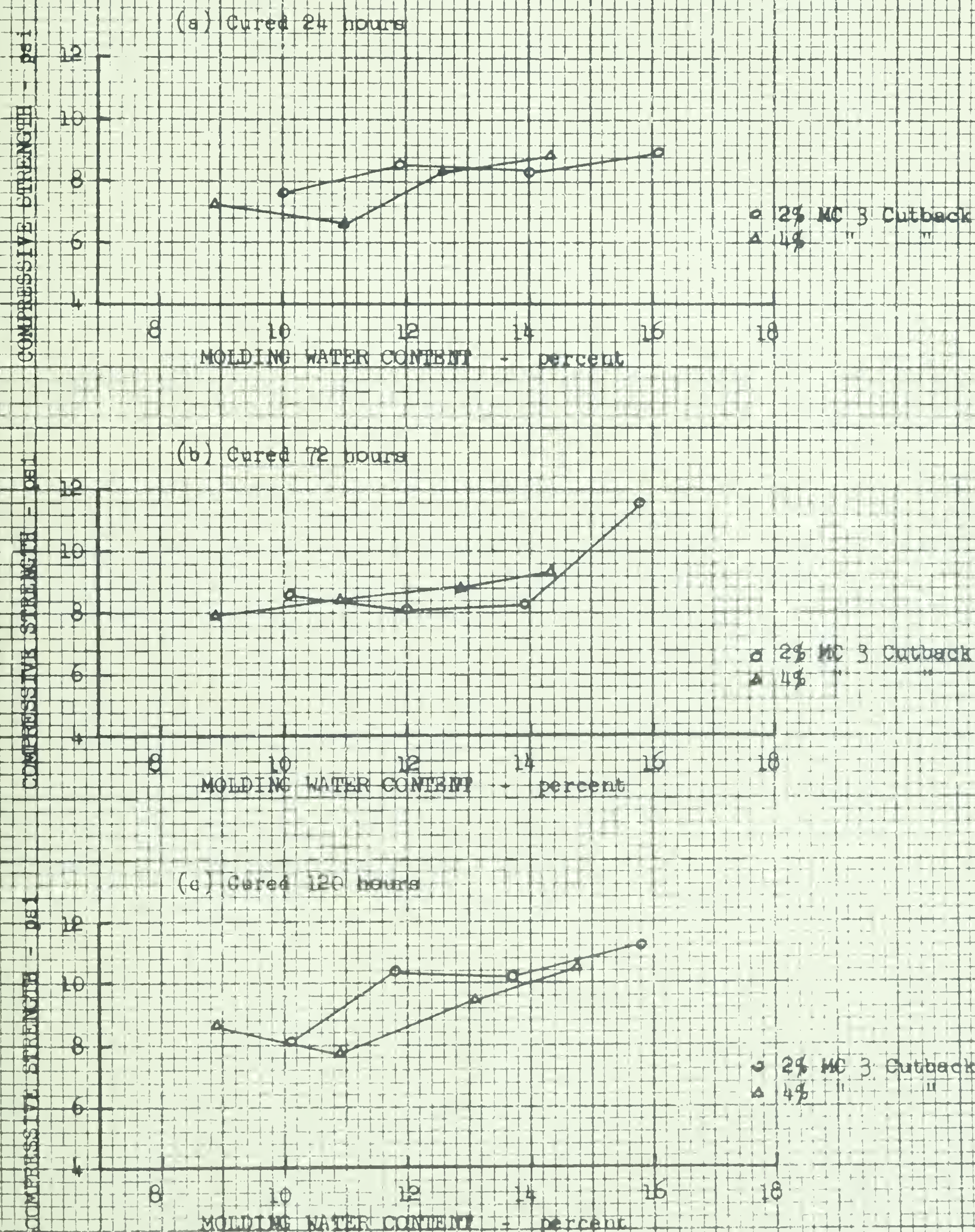


Figure 16

EFFECT OF MOLDING WATER CONTENT ON COMPRESSIVE STRENGTH

AFTER 21 DAYS IMMERSION

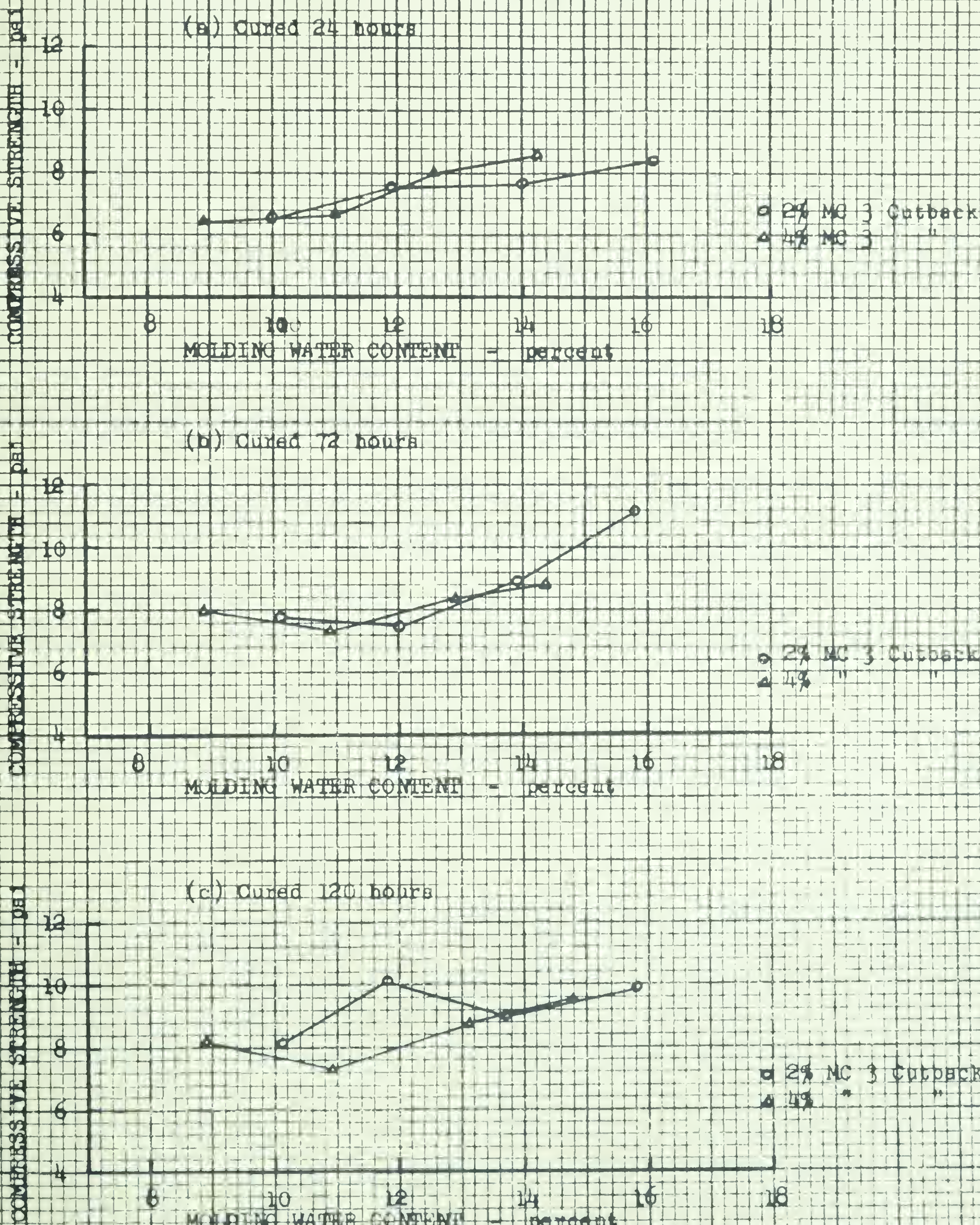


Figure 17

EFFECT OF MOLDING CUTBACK CONTENT

ON COMPRESSIVE STRENGTH

AFTER 7 DAYS IMMERSION

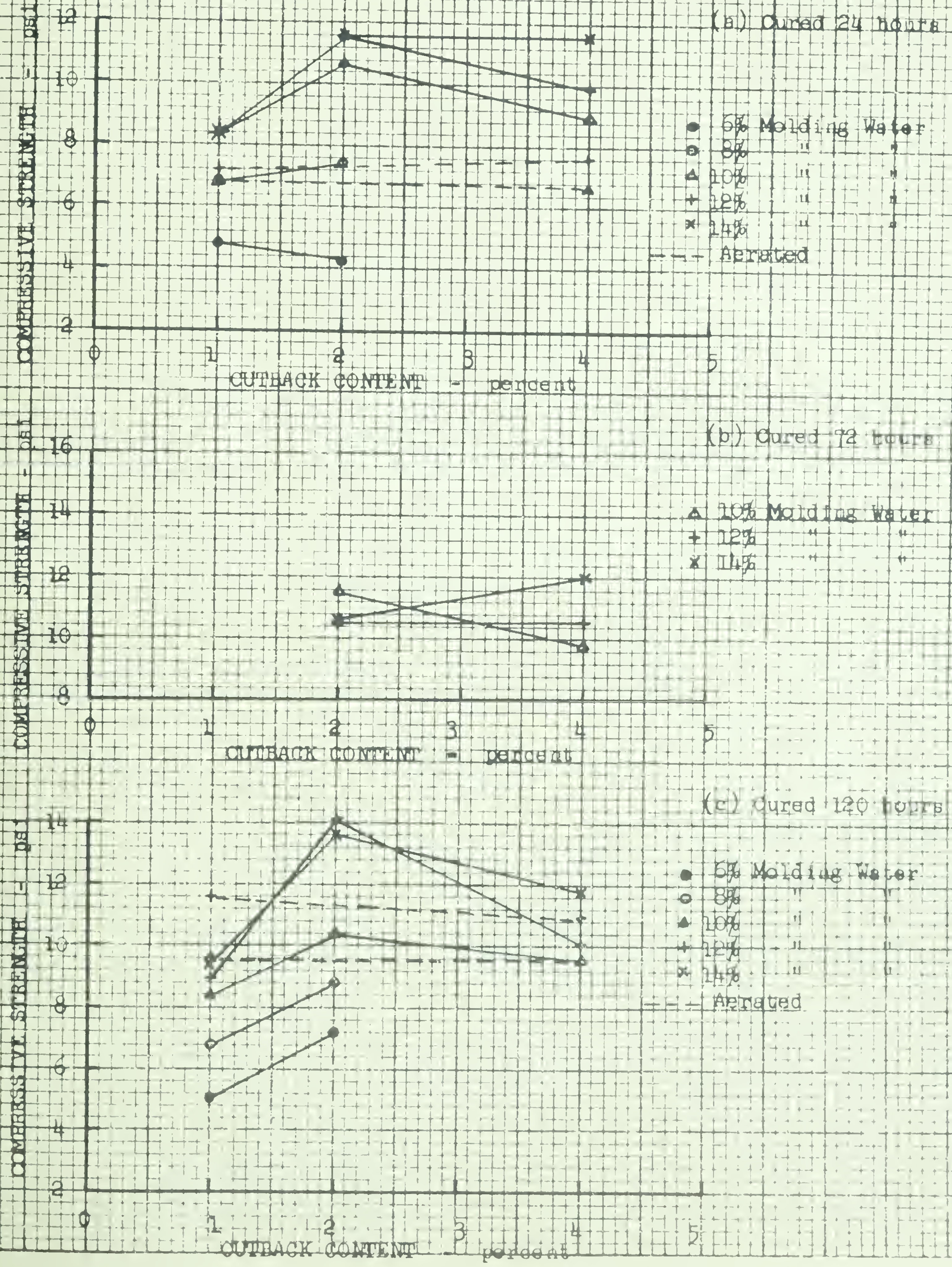


Figure 18

EFFECT OF MOLDING CUTBACK CONTENT
ON COMPRESSIVE STRENGTH
AFTER 14 DAYS IMMERSION

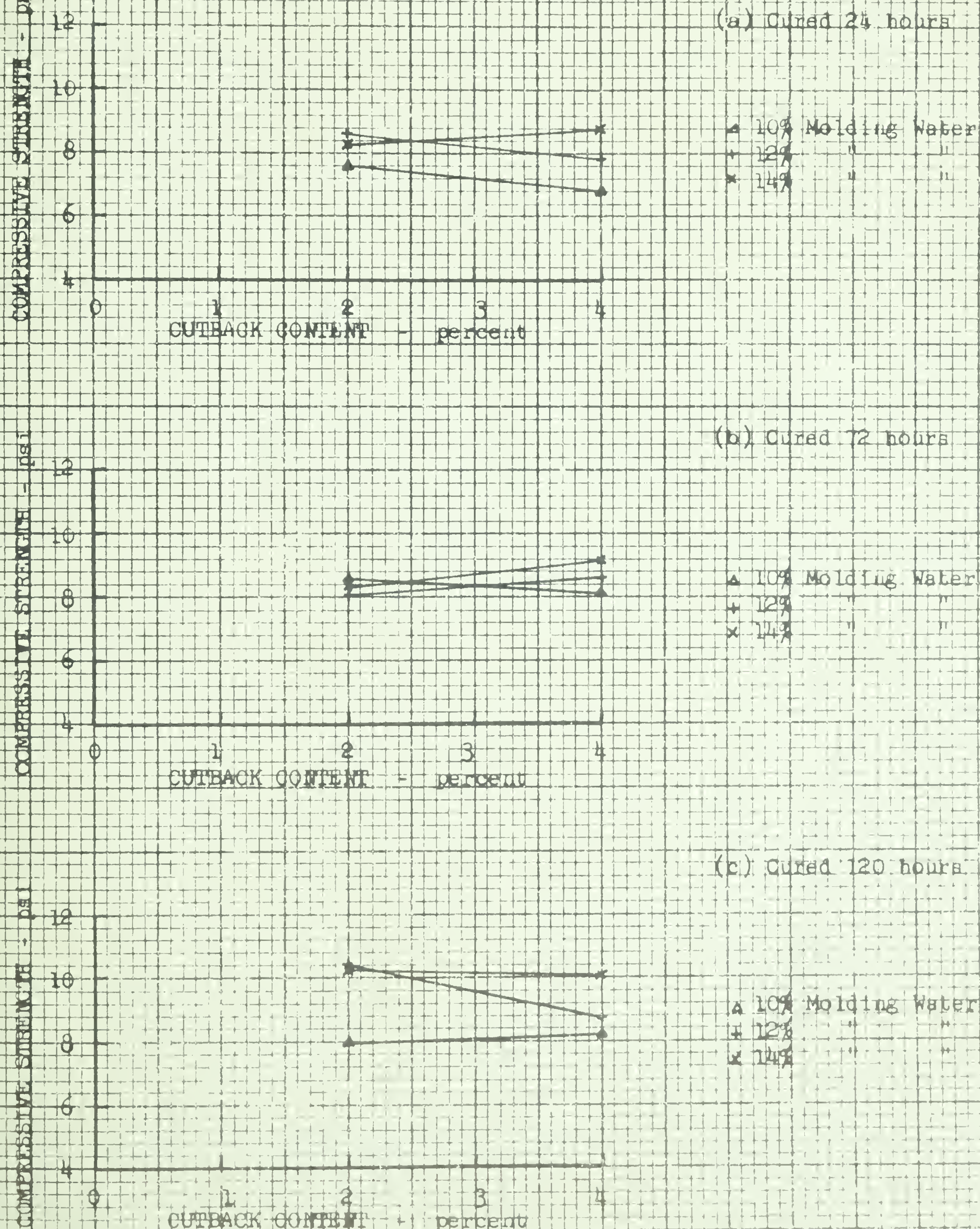
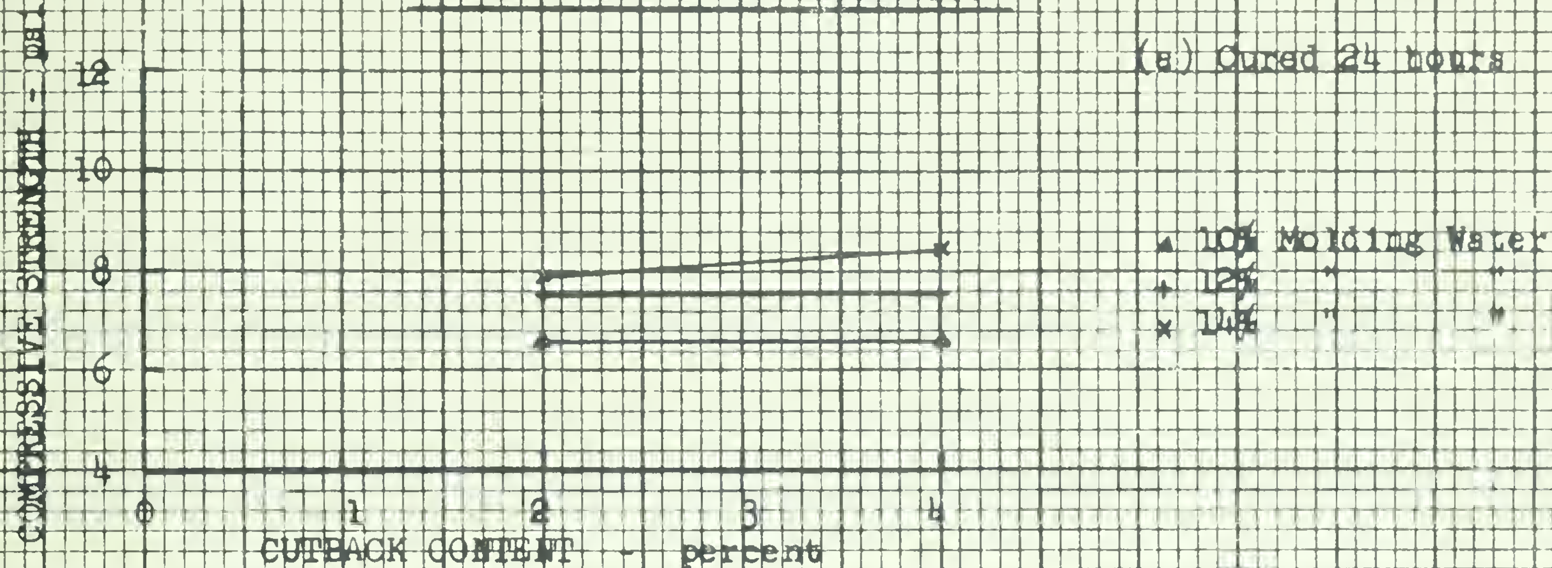


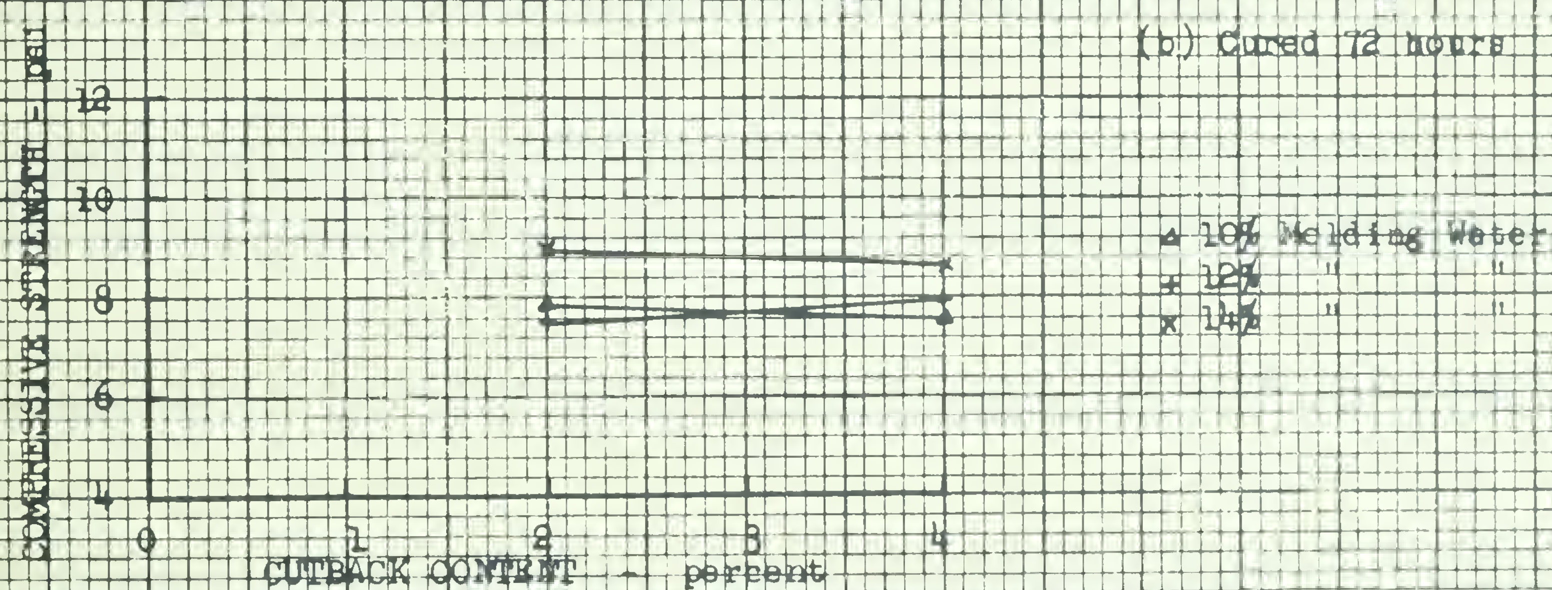
Figure 19

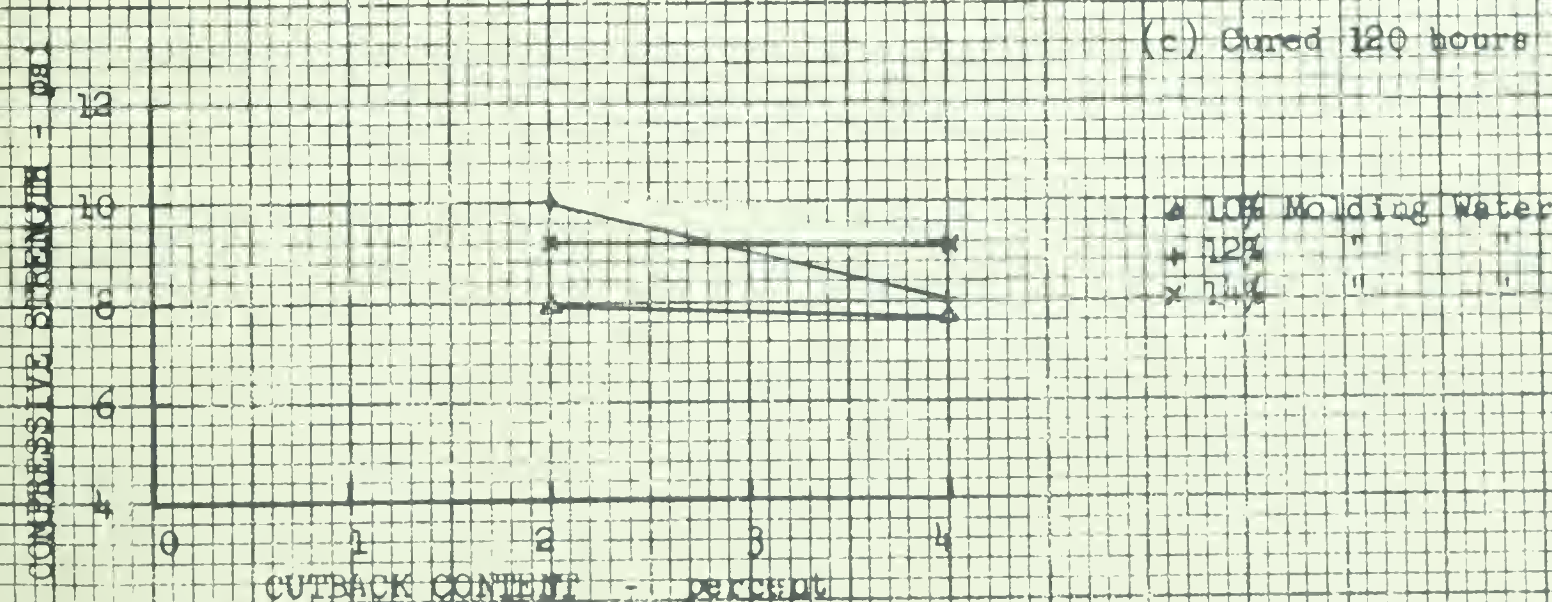
EFFECT OF MOLDING CUTBACK CONTENT

ON COMPRESSIVE STRENGTH

AFTER 21 DAYS IMMERSION







lower immersed compressive strengths at higher cutback contents. The highest immersed compressive strength obtained after seven days immersion was 15.2 pounds per square inch. The mixture that produced this highest strength contained 2 percent cutback asphalt and 15.8 percent molding water.

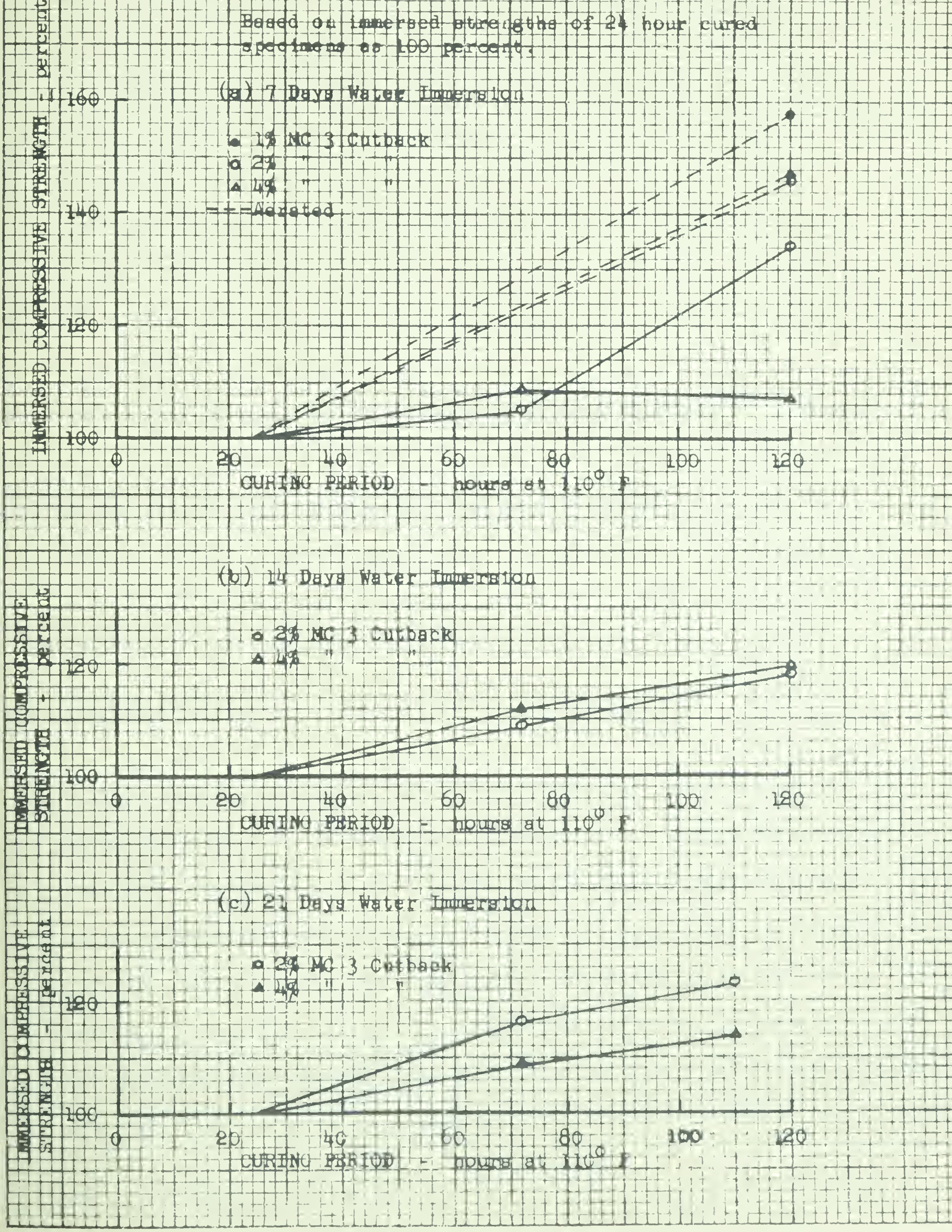
Effect of Aerating the Mixture Before Compacting on the Immersed Compressive Strength: Mixtures that were dried back before compacting showed a reduced immersed compressive strength when only cured for 24 hours. However these same mixtures when cured for 120 hours after molding provided samples with immersed compressive strengths as high as and in some cases higher than the mixtures that were molded without aeration.

Effect of Curing on the Immersed Compressive Strength: Curing for longer periods had a beneficial effect on the durability of the samples as measured by their unconfined compressive strength after immersion in water. In practically all cases samples that were cured for 72 hours had higher immersed compressive strength than samples from the same mixture that were cured only 24 hours. Similarly curing for 120 hours generally increased the immersed compressive strength over that of the 24 and 72 hour cured samples. This is illustrated in Figure 20 in which the immersed strengths of samples cured for 24 hours are shown as 100 percent. The mixtures that had been aerated prior to molding showed the greatest benefit drom longer curing periods.

Rate of Water Absorption: A number of curves showing the rates of water absorption by the various cured mixtures are shown in Appendix D. These rates are based on the volume of water filling the voids in the aggregate. Samples prepared from the mixtures containing two percent

Figure 20

EFFECT OF CURING ON IMMERSED COMPRESSIVE STRENGTH



and four percent cutback were still absorbing water after 21 days immersion in most cases although the rates of absorption were considerably reduced. Of note is the marked reduction in the rate of water absorption of the samples prepared from the aerated mixtures.

<u>Effect of Molding Water Content on Water Absorption</u>: Figures 21, 22, and 23 show the relationships between the molding water content and water absorption after 7, 14, and 21 days immersion. Water absorption appears to reach a maximum in samples molded at a water content of 14 percent. Mixtures that were aerated prior to molding did not show as much sensitivity to increased or decreased absorption with molding water content.

<u>Effect of Molding Cutback Content on Water Absorption:</u> Figures 24, 25, and 26 show the relation between water absorption, as expressed by the percent of water in the voids in the aggregate, and molding cutback asphalt content. The trend is towards higher water absorption with higher percentages of cutback in the mix. Although not shown in graphical form, the actual quantity of water absorbed by samples containing higher percentages of cutback was also greater. This was true as the percentage of voids filled with residual asphalt increases only a small amount with increasing cutback content in comparison to the large increase in water absorbed. Although some sloughing of material occurred with samples containing one and two percent cutback, the amount of material lost was not sufficient to account for the large difference in water absorption as determined by the weights of the samples. Jones(1962) found that increasing the amount of cutback in the mix decreased the rate of water absorption but he did not compare mixtures having the same molding water content.

Figure 21

EFFECT OF MOLDING WATER CONTENT

ON WATER ABSORPTION AFTER 7 DAYS IMMERSION

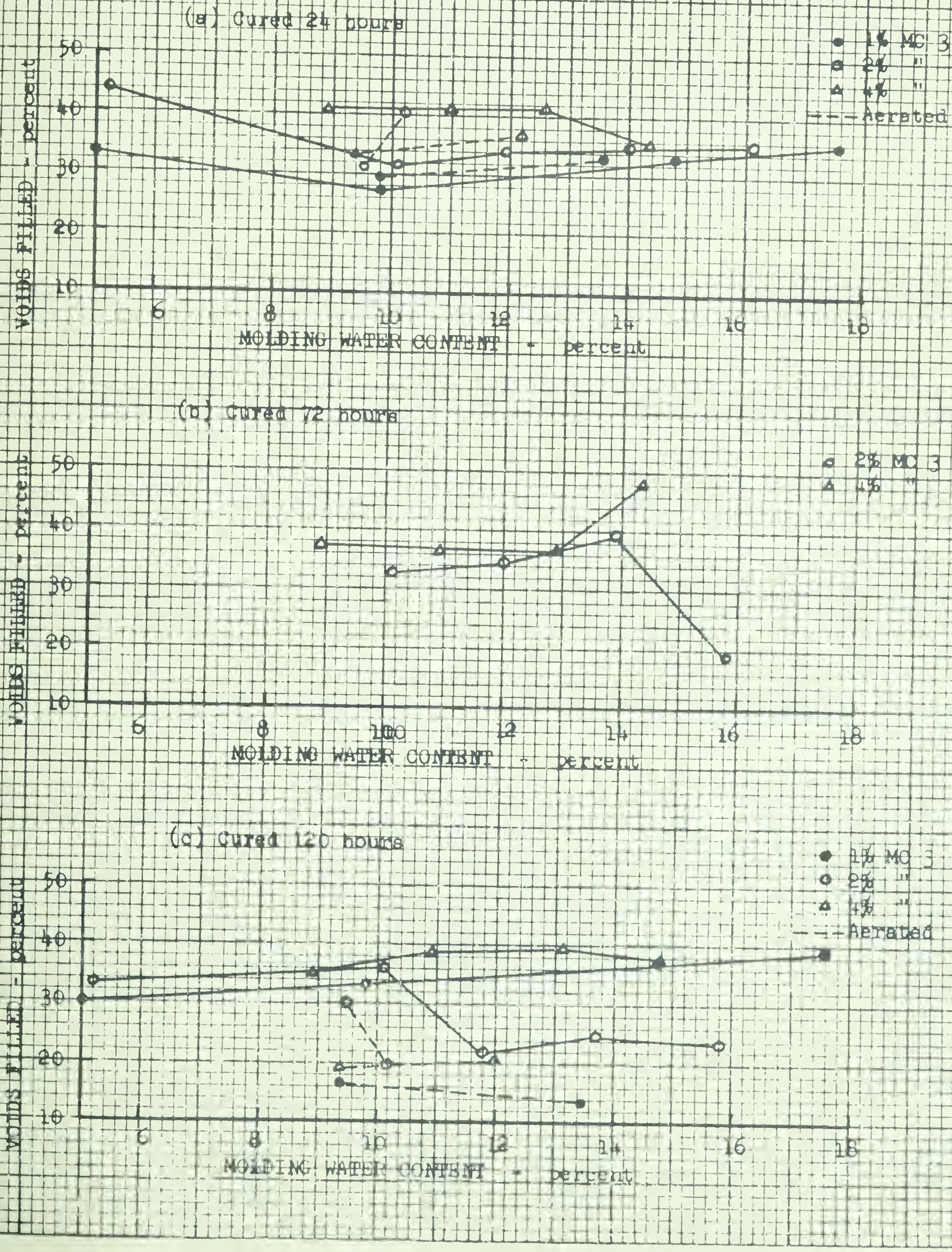


Figure 22

EFFECT OF MOLDING WATER CONTENT ON WATER ABSORPTION AFTER 14 DAYS IMMERSION

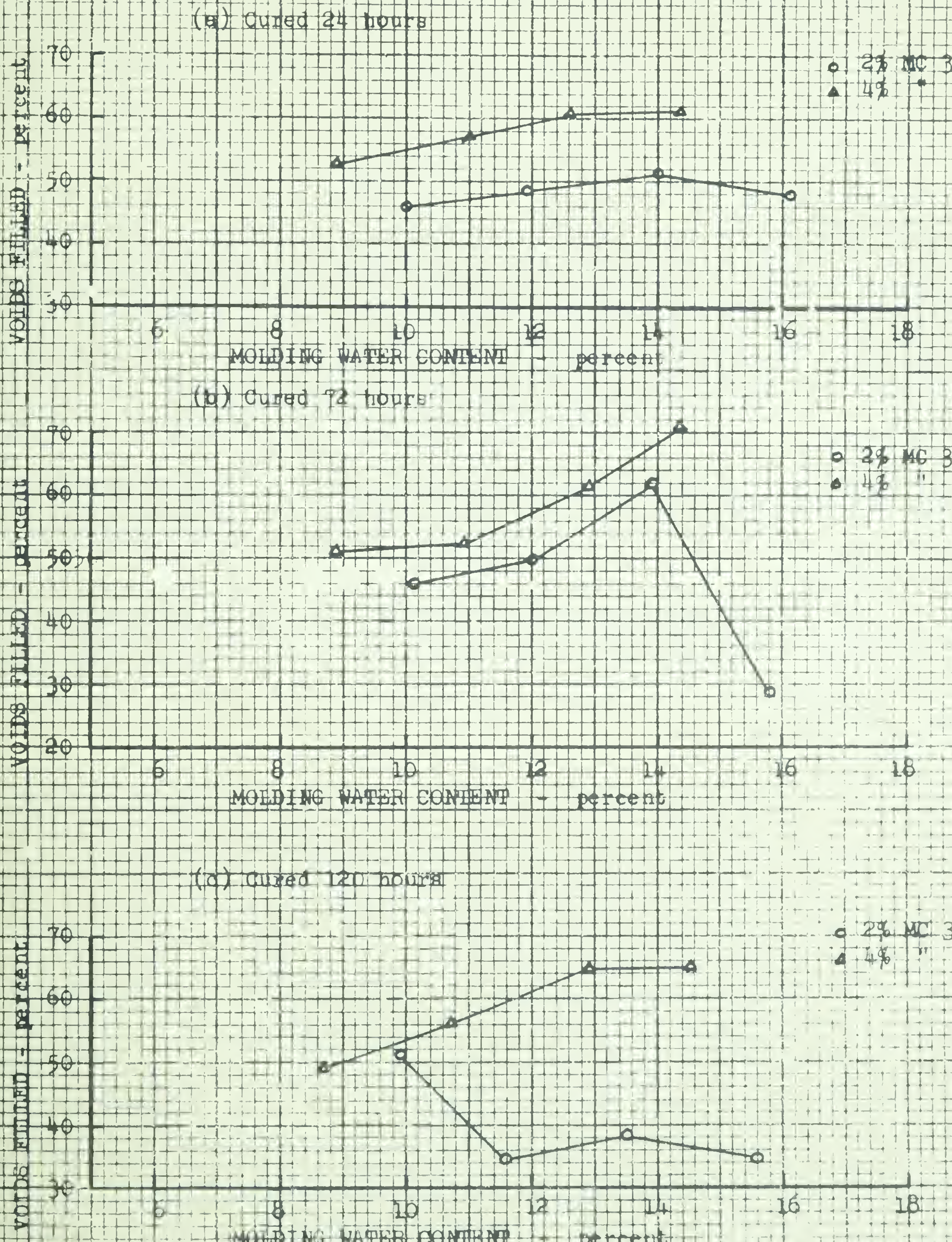


Figure 23

EFFECT OF MOLDING WATER CONTENT

ON WATER ABSORPTION AFTER 21 DAYS IMMERSION

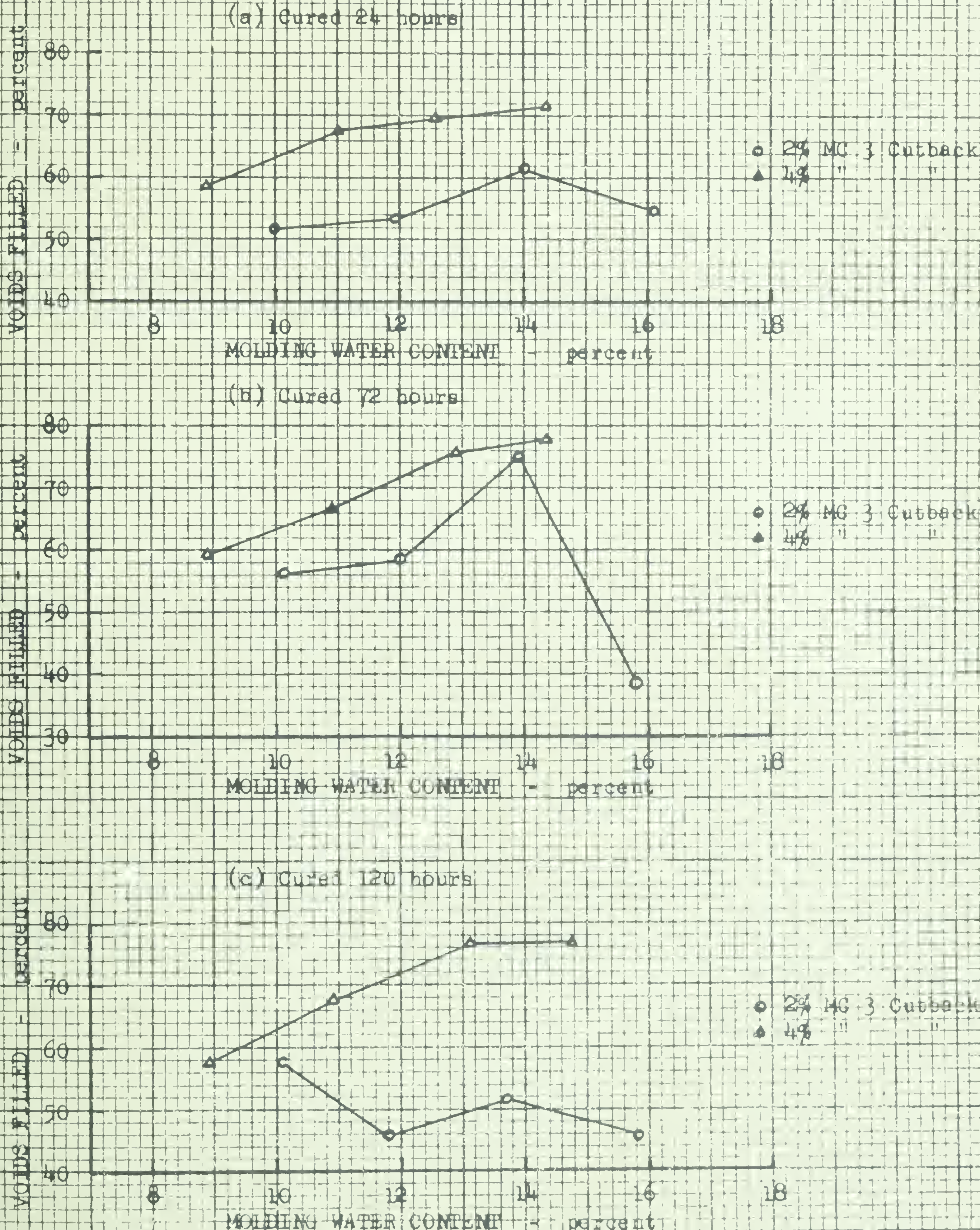


Figure 24

EFFECT OF MOLDING CUTBACK CONTENT

ON WATER ABSORPTION AFTER 7 DAYS IMMERSION

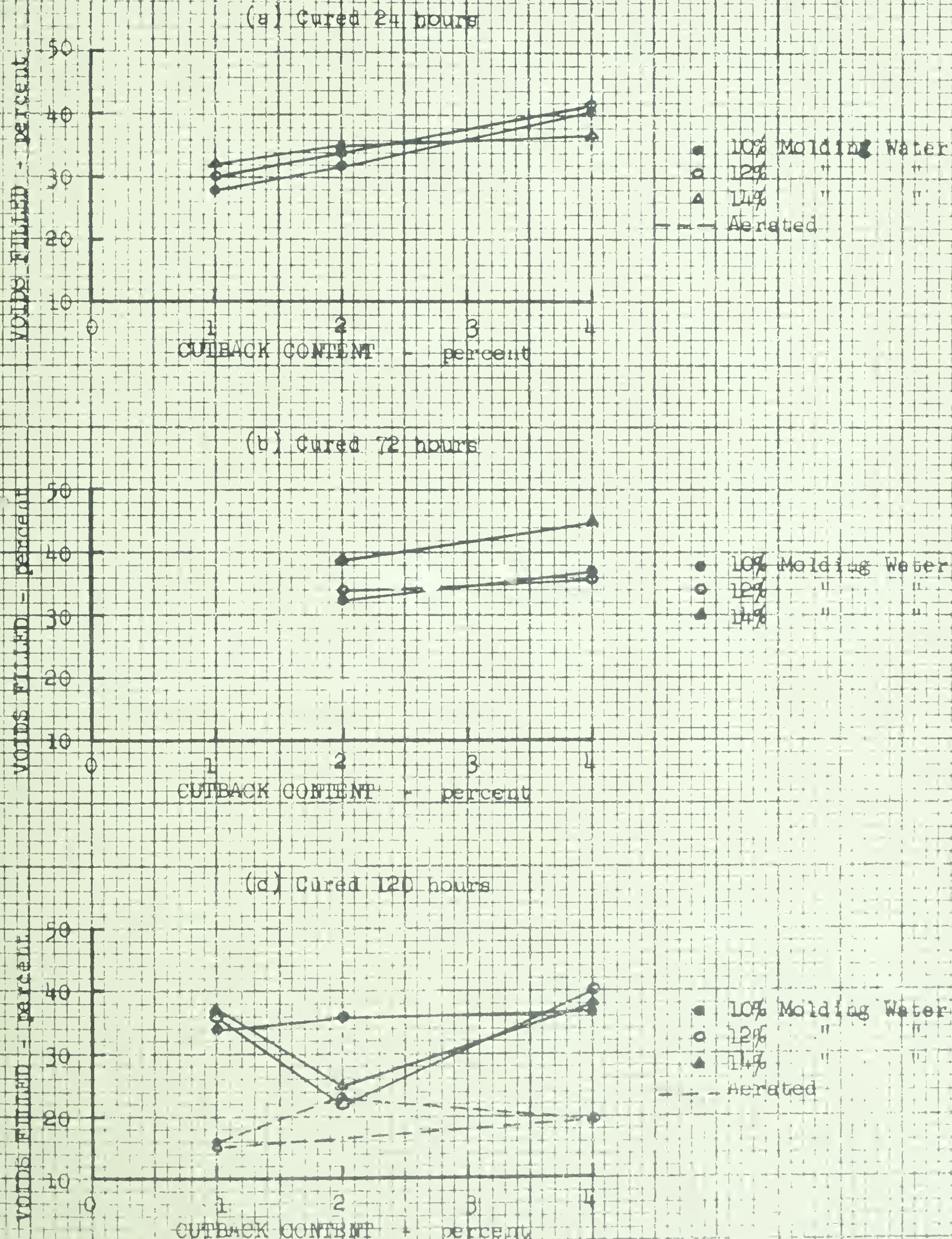


Figure 25

EFFECT OF MOLDING CUTBACK CONTENT ON WATER ABSORPTION AFTER 14 DAYS IMMERSION

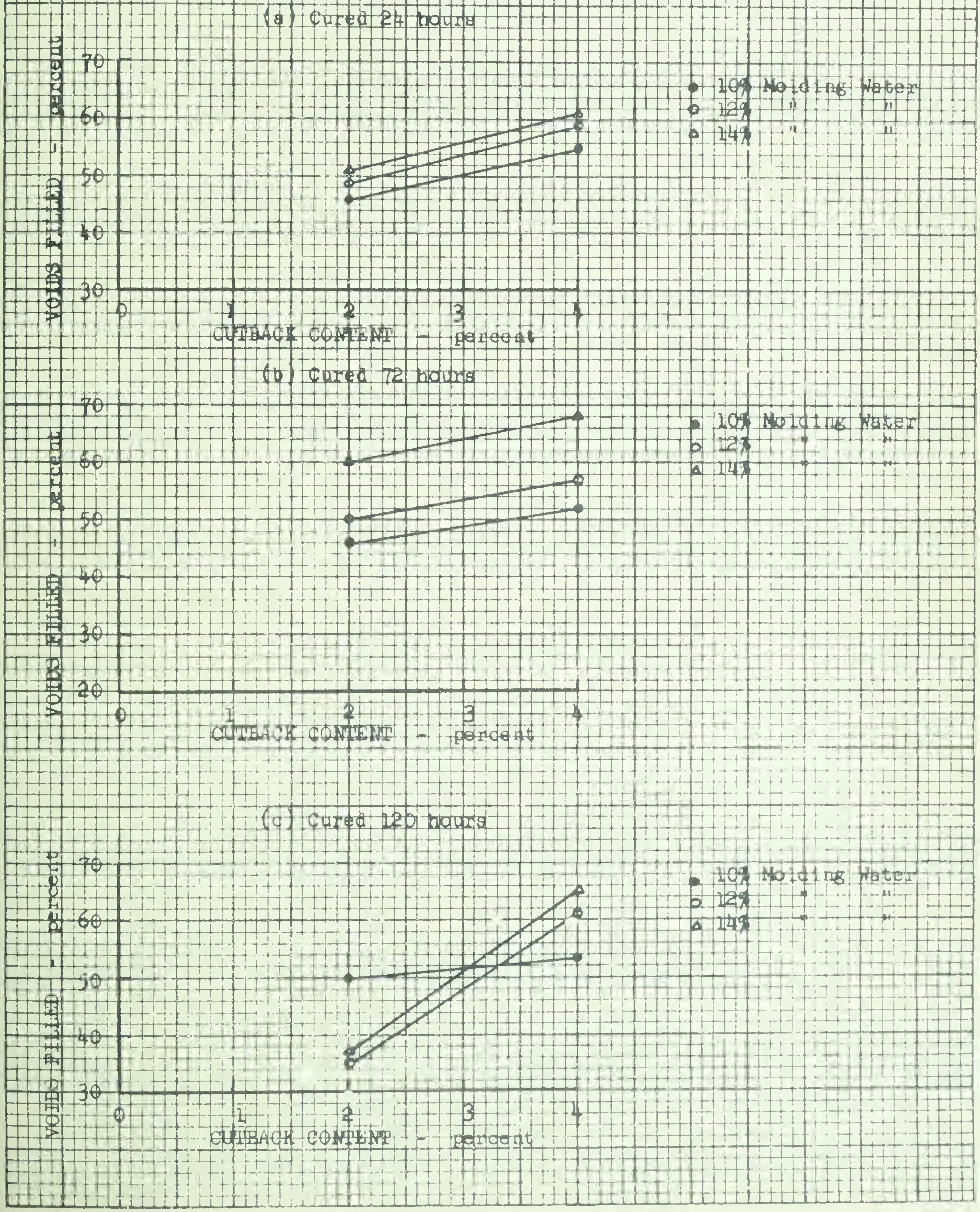
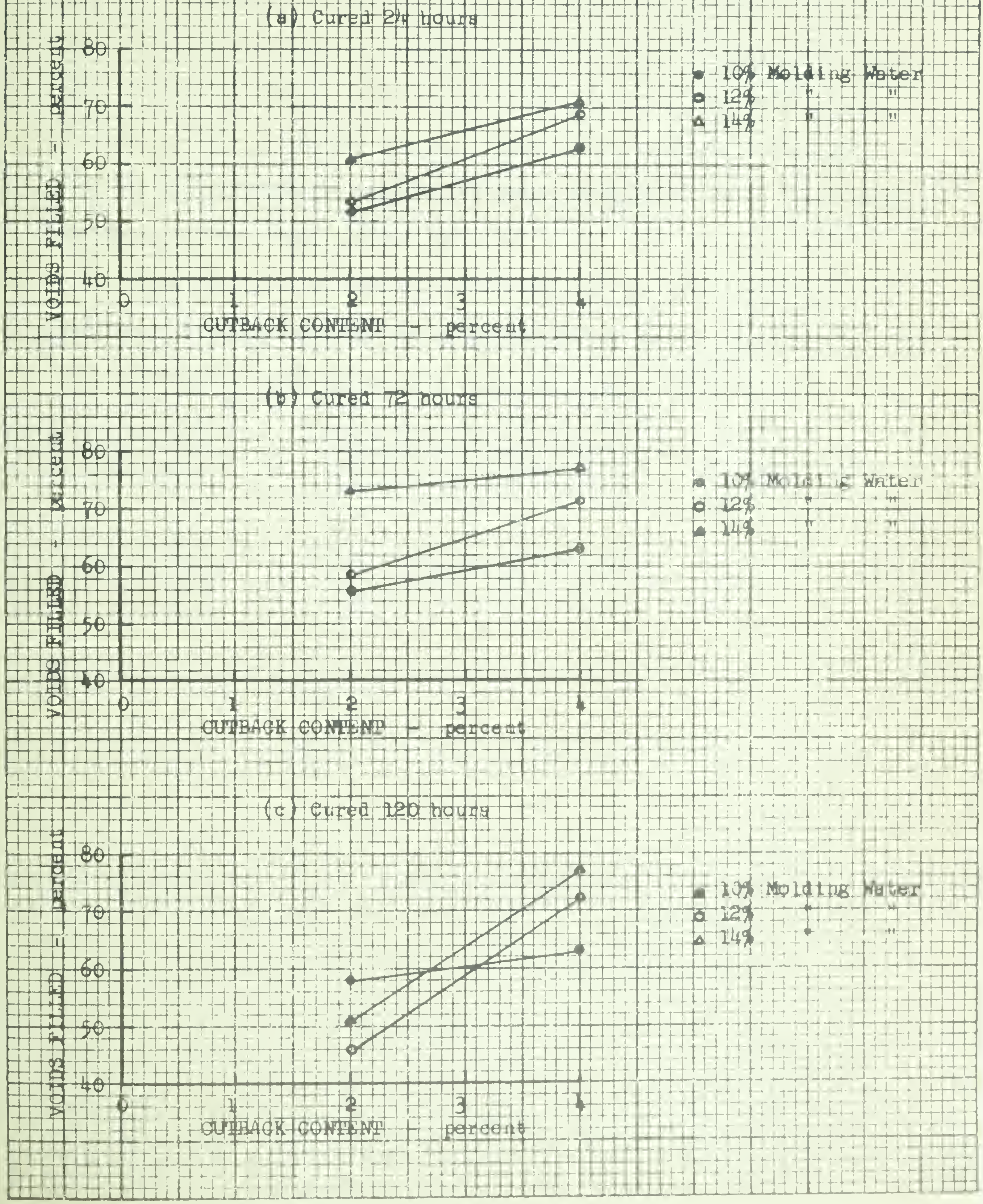


Figure 26

EFFECT OF MOLDING CUTBACK CONTENT ON WATER ABSORPTION AFTER 21 DAYS IMMERSION



Effect of Curing on Water Absorption: Based on water absorption of the samples that were cured for 24 hours as being 100 percent, as indicated in Table V, there does not appear to be a definate relationship between curing period and water absorption of the immersed samples that were molded at or near the mixing water content. Mixtures containing one percent of cutback asphalt showed predominantly increased water absorption with increased curing periods. Most mixtures containing two and four percent cutback on the other hand had lower rates of water absorption with longer curing periods.

There was no such wide variation with the aerated mixtures however. All mixtures that were aerated before molding showed reduced water absorption tendencies with longer curing periods.

TABLE V

EFFECT OF CURING ON WATER ABSORPTION

MC 3 Content	Molding Water Content	Curing Period	Change in Water Absorption With Increased Curing Period*		
			Immersed 7 Days	Immersed 14 Days	Immersed 21 Days
%	%	hrs			
1	5.0	120	87%		
	9.8	"	119		
	14.8	"	112		
	17.6	"	110		
2	5.2	120	76		
	10.1	72	103	103%	109%
	10.1	120	114	113	113
	12.0	72	102	106	106
	11.8	120	65	74	86
	13.9	72	111	122	121
	13.7	120	70	75	84
	15.8	72	53	62.5	74
	15.8	120	64	73	85
4	8.9	72	91.5	98	101
	8.9	120	85	93.5	99
	10.9	72	89	91	98
	10.9	120	96	101	99
	12.9	72	85	101	108
	13.1	120	95	107	109
	14.35	72	126	116	110
	14.75	120	103	107	108
1	9.4	120	57		
	13.5	"	45		
2	9.5	120	95	Aerated Mixtures	
	10.2	"	49		
4	9.4	120	58		
	12.2	"	56		

* Change in water absorption is shown as a percentage of the water absorption for samples cured for 24 hours. Rates of water absorption are based on the amount of water filling the voids in the aggregate.

Summary of Results

Aeration of Mixtures Before Molding: Aerating the mixtures before molding, increased the air voids, reduced the dry density, and reduced the unconfined compressive strength of samples cured but not immersed. However the compressive strength of such samples when cured for 120 hours at a temperature of 110°F and subjected to water immersion for a period of seven days, showed improvement over that of samples molded at the same water content from mixtures that had not been aerated. This could be due to the lower percentage of cutback diluent in the aerated mixtures at the time of immersion. Water absorbed by samples made from aerated mixtures was greater than that of the non-aerated mixtures when a short (24 hour) curing period was used. However if the samples were cured for a period of 120 hours, those made from the aerated mixtures were much less water absorptive than those molded from the non-aerated mixtures when compared at the same molding water content. As the compressive strength of asphalt stabilized soil after a period of water immersion is probably more realistic of long term field conditions in this country than the compressive strength immediately after curing, it would appear that aerating the mixture before compaction can be beneficial to the final product. The direct advantage of aerating before compaction is of course the greater stability during the compaction process. The results of this investigation showed that there were no harmful effects from aerating prior to compaction. Limitations on time did not permit as extensive an investigation as was desired on the aeration phase of the programme.

Curing After Molding: Curing for longer periods (up to 5 days at 110°F) was highly beneficial for samples that had been molded from

aerated mixtures. Immersed compressive strength was increased and water absorption tendencies were lowered. Curing for longer periods was less beneficial for samples molded immediately after mixing. There was improvement in immersed compressive strength but a definite trend was not apparent on the water absorption characteristics. Curing was more beneficial to samples molded from mixtures containing smaller percentages of cutback asphalt. Longer curing periods increased the compressive strength of all samples that were not subjected to water immersion.

Amount of Water in the Mix: The unconfined compressive strengths of cured samples not subjected to water immersion reached an apparent maximum at a molding water content of approximately 14 percent, based on the oven dry weight of sand in the mix. Optimum molding water content for maximum dry density appeared to vary slightly with the amount of cutback in the mixture. One percent cutback asphalt in the mixture produced an optimum near 17 percent molding water content. Two and four percent cutback in the mixture produced apparent optimums at slightly lower molding water contents although maximum densities were not reached. As the maximum dry density for the sand alone was at an optimum molding water content of 18 percent, it would appear that the amount of diluent governs the reduction in optimum water content for maximum dry density rather than the total amount of cutback asphalt in the mix. Higher molding water contents produced increased compressive strength after water immersion whether or not the mixtures had been aerated prior to compaction.

Amount of Cutback Asphalt in the Mix: Of the mixtures studied in this investigation, a cutback content of about two percent, based on

the oven dry weight of sand, gave the best final product as measured by highest immersed compressive strength and relatively low rate of water absorption. Increasing the amount of cutback in the mixture correspondingly increased the dry density, reduced the air voids at molding and voids in the aggregate. It also reduced the compressive strength of the cured samples. A cutback content of two percent gave maximum compressive strength after seven days water immersion. Longer immersion periods reduced the difference in compressive strength between the two and four percent cutback mixtures. However even after 21 days water immersion, the two percent mixtures showed slightly higher strengths than the four percent mixtures.

Increased cutback content appeared to result in increased water absorption when comparing mixtures molded at the same water content. As the voids in the aggregate as well as the air voids are reduced with larger amounts of cutback in the mix, this phenomenon appears to be an anomaly. However the facility with which the compacted sample absorbs water may be aided by the surface tension forces within the sample. These might be increased by the reduced air voids in samples containing greater amounts of cutback. Another possible explanation may be that a mixture containing a larger percentage of cutback will have a greater quantity of diluent that has not been evaporated. Thus the residual asphalt cement does not act as a cement and waterproofer until the diluent has evaporated out of the sample.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The conclusions arrived at as a result of this investigation are limited to the extent of the materials used and testing conditions which prevailed. In particular they apply to the one sand and cutback asphalt used in the investigation. Using different materials and different test conditions may or may not give similar results.

Conclusions

1. Mixtures that were aerated prior to compaction and cured for a period of five days at 110°F showed reduced water absorption tendencies and increased immersed compressive strengths when compared with non-aerated mixtures.

2. Curing for longer periods increased the compressive strength of all samples not subjected to water immersion.

3. Curing was most beneficial to samples molded from mixtures containing smaller percentages of cutback asphalt.

4. Higher molding water contents resulted in higher immersed compressive strengths regardless of whether or not the mixtures had been aerated before compaction.

5. There was no relationship between the unconfined compressive strength of samples tested immediately after curing and that of samples tested after a period of water immersion.

6. Curing for longer periods increased the immersed compressive strength for all samples whether molded from aerated mixtures or not. Curing for periods longer than 24 hours increased the air voids in the samples only slightly. There is no apparent relation between air voids content and compressive strength.

Recommendations

As the results of this investigation indicated that evaporation of the cutback diluent in a sand-cutback-water mixture is possibly the most important single contributor to a durable product, a further investigation should be conducted wherein cutback and water content determinations are made by distillation to ensure more reliable results. In this way an attempt to establish a relationship between residual asphalt content and immersed compressive strength could be carried out. Such a test programme should include a wider range of molding water contents than was used in this investigation.

Further research should be undertaken with aerated mixtures. Good distribution of asphalt occurs near the optimum water content of the sand and aerating prior to compaction has been found to be beneficial. Mixtures should be prepared at optimum water content and aerated to four or five different molding water contents so that a closer indication of the degree of aeration for best results can be ascertained.

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APPENDIX A

PRELIMINARY TESTING

Specific Gravity

Sieve Analysis

Standard AASHO Compaction

Alberta Research Council Compaction

UNIVERSITY of ALBERTA
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SOIL MECHANICS LABORATORY

SPECIFIC GRAVITY

PROJECT THESIS
SITE
SAMPLE FINE SAND
LOCATION McGINN PIT
HOLE DEPTH
TECHNICIAN R. WHITE DATE 19 JUNE 62

Sample No.	1	
Flask No.		
Method of Air Removal	VACUUM	
W_{b+w+s} gm.	787.50	
Temperature T	24.0°C	
W_{b+w} gm.	695.57	
Evaporating Dish No.	KW 1.	
Wt. Sample Dry + Dish gm.	375.76	
Tare Dish gm	228.42	
W_s gm	147.34	
G_s	2.66	

W_{b+w+s} = Weight of flask + water + sample at T°.
W_{b+w} = Weight of flask + water at T° (flask calibration curve).
W_s = Weight of dry soil
G_s = Specific gravity of soil particles $= \dfrac{W_s}{W_s + W_{b+w} - W_{b+w+s}}$

Determination of W_s from wet soil sample:

Sample No.			Sample No.		
Container No.			Container No.		
Wt. Sample Wet + Tare			Wt. Test Sample Wet + Tare		
Wt. Sample Dry + Tare			Tare Container		
Wt. Water			Wt. Test Sample Wet		
Tare Container			W_s		
Wt. of Dry Soil					
Moisture Content w %					

Description of Sample: FINE SAND
AASHO CLASSIFICATION - A-3.
SAMPLE OVEN DRIED INITIALLY.

Remarks

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SOIL MECHANICS LABORATORY

SIEVE ANALYSIS

PROJECT THESIS
SITE
SAMPLE FINE SAND
LOCATION McGINN PIT NO. 2
HOLE DEPTH
TECHNICIAN DATE 26 JUN 62

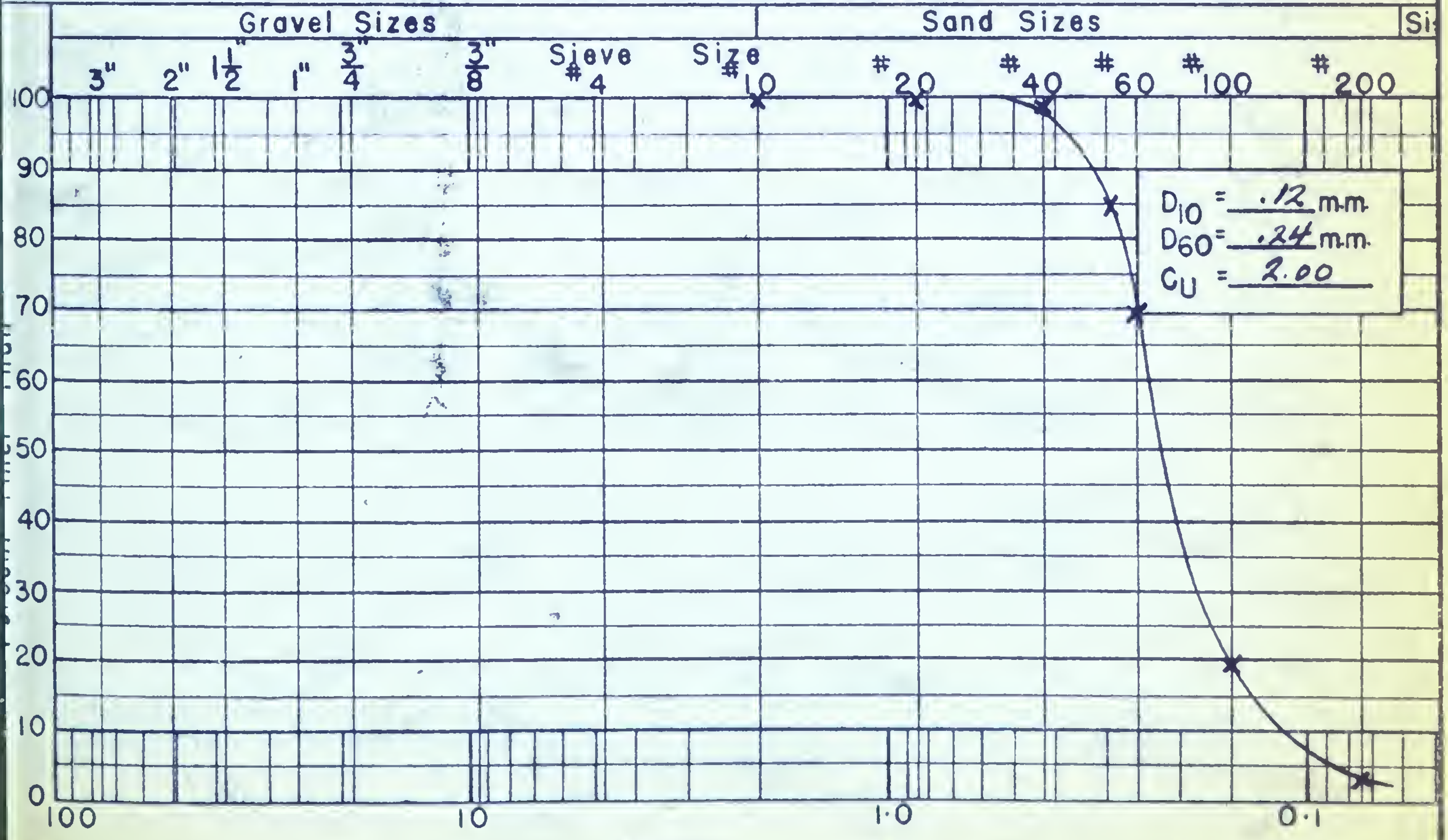
Total Dry Weight of Sample	Sieve No.	Size of Opening Inches	Size of Opening Mm.	Weight Retained gms.	Total Wt. Finer Than gms.	Percent Finer Than	% Finer Than Basis Orig. Sample
Initial Dry Weight							
Retained No. 4							
Tare No.							
Wt. Dry + Tare							
Tare		3/4	19·10				
Wt. Dry		3/8	9·52				
	4	·185	4·76				
Passing	4						
Initial Dry Weight							
Passing No. 4	10	·079	2·000			100	
Tare No.	20	·0331	·840			100	
Wt. Dry + Tare	40	·0165	·420			99.0	
Tare	60	·0097	·250			69.5	
Wt. Dry	100	·0059	·149			19.1	
	200	·0029	·074			2.7	
Passing	200						

Description of Sample SAMPLE OBTAINED BY QUARTERING BATCH SAMPLE. SEVERAL INDEPENDENT CHECKS MADE ALSO

Time of Sieving

Method of Preparation

Remarks



Grain Size-Mm.

Note: M·I·T· Grain Size Scale

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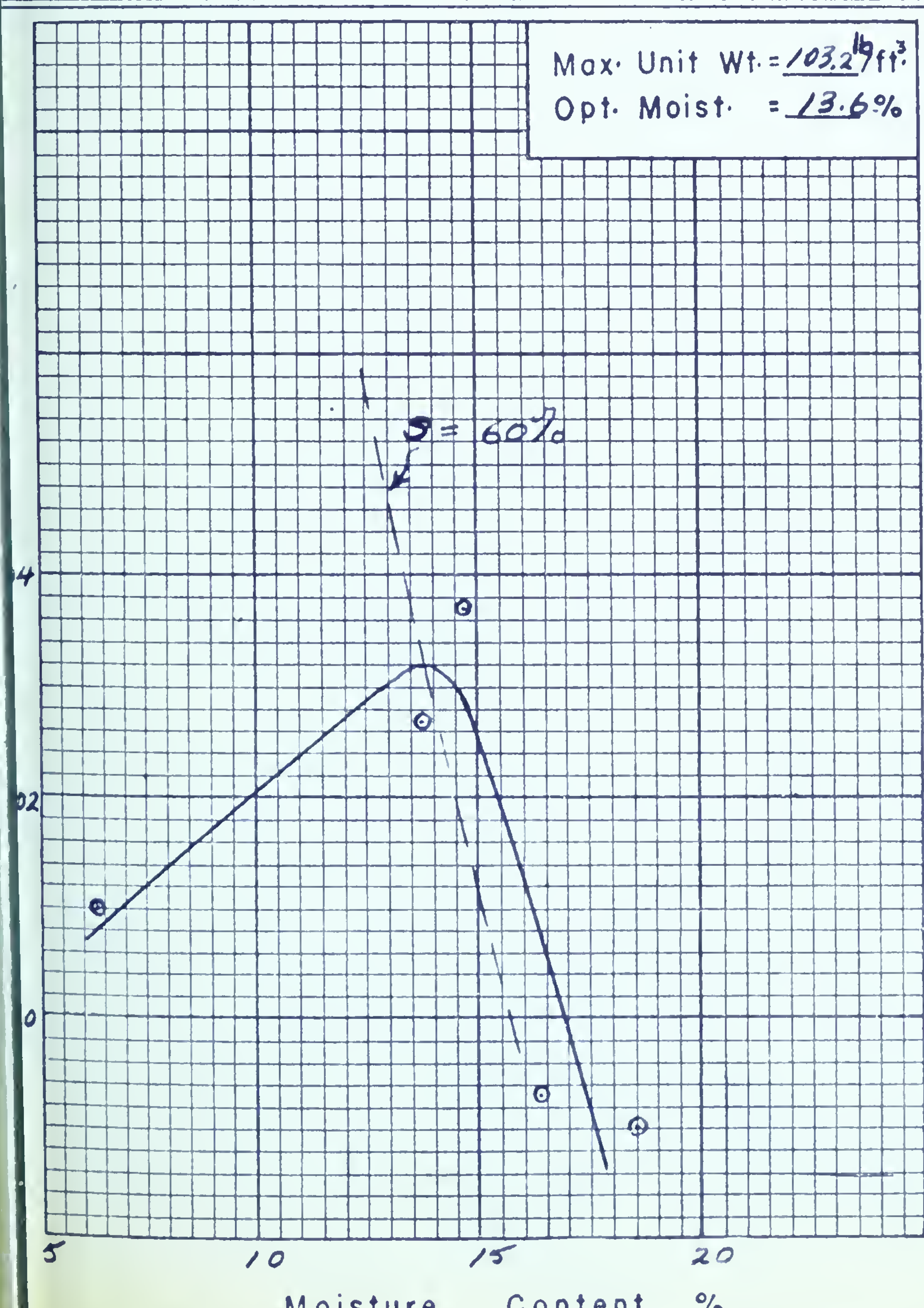
SOIL MECHANICS LABORATORY
COMPACTION TEST

PROJECT THESIS
SITE
SAMPLE FINE SAND
LOCATION McGINN PIT No. 2
HOLE DEPTH
TECHNICIAN R. WHITE DATE 21 JUN 62

Trial Number	1	2	3	4	5		
Mold No.							
Wt. Sample Wet + Mold gm	3360.8	3500.8	3531.0	3478.7	3507.8		
Wt. Mold gm	1734.8	1734.8	1734.8	1734.8	1734.8		
Wt. Sample Wet gm	1626.0	1766.0	1796.2	1743.9	1773.0		
Volume Mold cu. ft.	0.0333	0.0333	0.0333	0.0333	0.0333		
Wet Unit Weight lb./ft^3	107.3	116.8	118.9	115.6	117.2		
Dry Unit Weight lb./ft^3	101.0	102.7	103.7	99.3	99.0		

Container No.	CW1	CW2	CW3	CW4	CW5		
Wt. Sample Wet + Tare gm	910.0	670.5	1618.4	1615.8	1578.6		
Wt. Sample Dry + Tare gm	868.5	615.2	1426.5	1404.0	1349.0		
Wt. Water gm	41.5	55.3	191.9	211.8	229.6		
Tare Container gm	215.9	213.0	107.7	110.8	107.1		
Wt. Dry Soil gm	652.6	402.2	1318.8	1293.2	1241.9		
Moisture Content %	6.35	13.75	14.55	16.35	18.5		



Method of Compaction STANDARD AASHO (PROCTOR).

Diam. Mold 4 in.
Height Mold 4½ in.
Volume Mold 0.0333 cu. ft.
No. of Layers 3
Blows per Layer 25
Ht. of Free Fall 12 in.
Wt. of Tamper 5½ lb.
Shape of Tamping Face CIRCULAR
Description of Sample
McGINN PIT SAND.
G_s = 2.66
NON PLASTIC.
C_u = 2.00
AASHO CLASSIFICATION
A-3

Remarks

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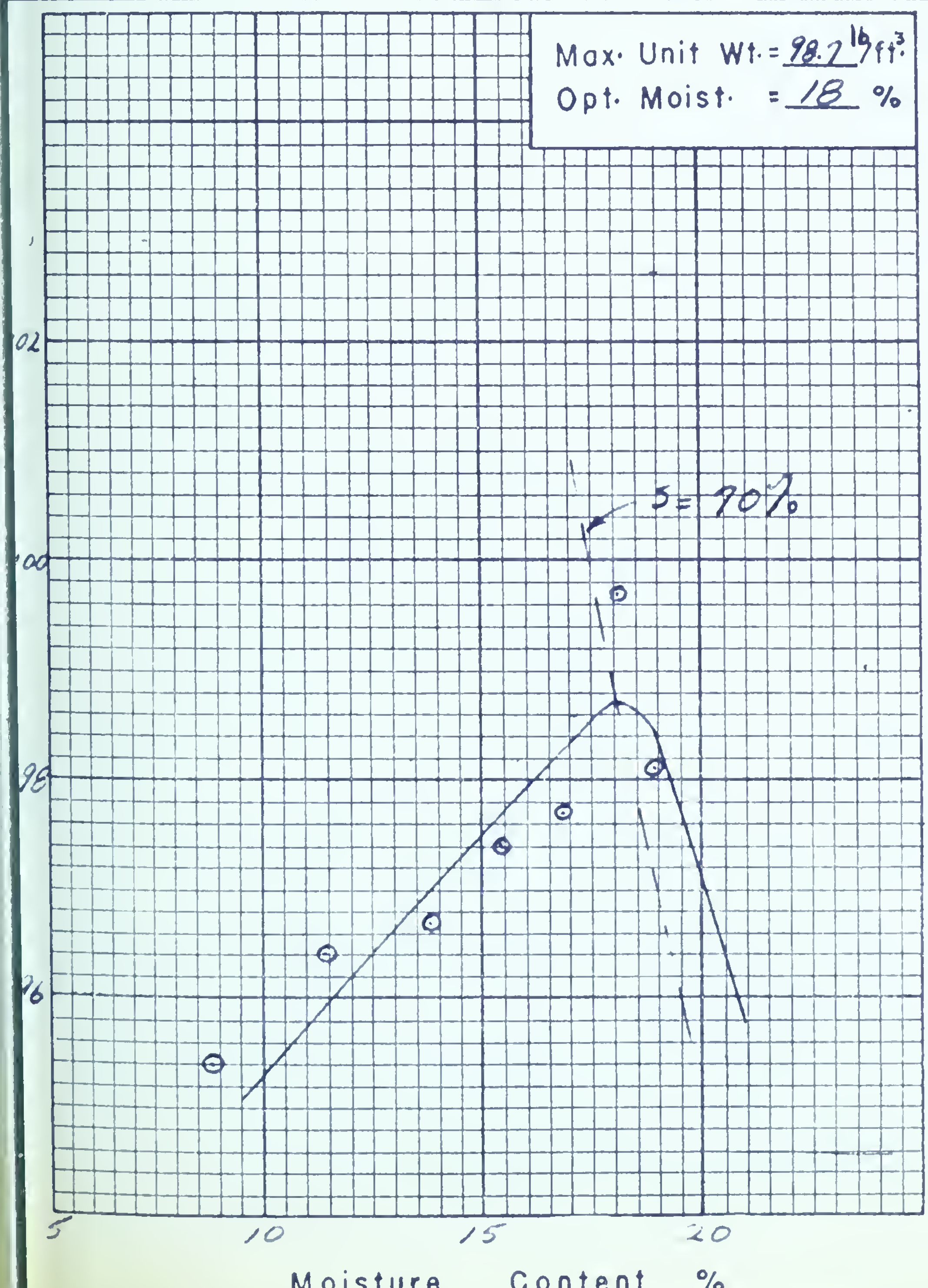
SOIL MECHANICS LABORATORY

COMPACTION TEST

PROJECT THESIS
SITE
SAMPLE FINE SAND
LOCATION McGINN PIT NO.2.
HOLE DEPTH
TECHNICIAN R. WHITE DATE 14 JUN 62

Trial Number	1	2	3	4	5	6	7
Mold No·							
Wt· Sample Wet + Mold gm	1762.0	1762.6	1763.2	1772.0	1773.1	1775.6	1781.5
Wt· Mold gm	1421.0	1421.0	1421.0	1421.0	1421.0	1421.0	1421.0
Wt· Sample Wet gm	341.0	341.6	342.2	351.0	352.1	354.6	360.5
Volume Mold cu.ft.	.00726	.00726	.00726	.00726	.00726	.00726	.00726
Wet Unit Weight lb/ft^3	103.7	103.8	103.9	106.5	107.0	107.6	109.5
Dry Unit Weight lb/ft^3	95.4	95.4	95.4	96.6	96.4	96.1	96.5
Container No·	A22	G20	V66	G22	S12	G21	S11
Wt· Sample Wet + Tare gm	172.59	199.14	189.58	167.42	169.18	177.40	153.10
Wt· Sample Dry + Tare gm	164.47	188.65	179.53	157.81	159.75	165.68	142.18
Wt· Water gm	8.12	10.49	10.05	9.61	9.43	11.72	10.92
Tare Container gm	71.93	67.94	66.41	67.47	75.19	68.00	60.40
Wt· Dry Soil gm	92.54	115.71	113.12	88.32	84.56	97.68	81.78
Moisture Content %	8.76	8.94	8.87	10.9	11.15	12.0	13.4

Max· Unit Wt· = 98.7 lb/ft^3
Opt· Moist· = 18 %



Method of Compaction
4 LAYERS, 10 BLOWS PER LAYER.

Diam. Mold 2.00 in.
Height Mold 4.00 in.
Volume Mold .00726 cu. ft.
No· of Layers 4
Blows per Layer 10
Ht· of Free Fall 12 in.
Wt· of Tamper 5½ lb.
Shape of Tamping Face CIRCULAR
Description of Sample
McGINN PIT SAND
G_s = 2.66
NON PLASTIC
C_u = 2.00
AASHO CLASSIFICATION: A-3

Remarks
Each point average of 3 trials.

UNIVERSITY of ALBERTA DEP'T. of CIVIL ENGINEERING SOIL MECHANICS LABORATORY **COMPACTION TEST**	PROJECT THESIS SITE SAMPLE FINE SAND LOCATION McGINN PIT No. 2. HOLE DEPTH TECHNICIAN R. WHITE DATE 19 JUN 62

	Trial Number	8	9	10	11	12	13	14
Determination	Mold No.							
	Wt. Sample Wet + Mold gm	1781.0	1787.6	1789.8	1791.0	1792.8	1795.0	1795.1
	Wt. Mold gm	1421.0	1421.0	1421.0	1421.0	1421.0	1421.0	1421.0
	Wt. Sample Wet gm	360.0	366.6	368.8	370.0	371.8	374.0	374.1
	Volume Mold cu. ft.	.00726	.00726	.00726	.00726	.00726	.00726	.00726
	Wet Unit Weight lb/ft^3	109.2	111.2	112.0	112.3	112.8	113.8	113.8
	Dry Unit Weight lb/ft^3	96.4	97.1	97.4	97.2	97.5	97.7	97.7
Determination	Container No.	A1	S13	V18	S6	V50	V660	S6
	Wt. Sample Wet + Tare gm	169.16	182.42	174.08	199.05	197.13	189.32	168.50
	Wt. Sample Dry + Tare gm	156.74	167.67	159.21	180.78	179.75	171.86	153.64
	Wt. Water gm	12.42	14.75	14.87	18.27	17.38	17.46	14.86
	Tare Container gm	63.64	66.05	59.92	63.49	68.73	66.41	63.49
	Wt. Dry Soil gm.	93.10	101.62	99.29	117.29	111.02	105.45	90.15
	Moisture Content %.	13.4	14.5	15.0	15.6	15.7	16.6	16.5

Max. Unit Wt. = ____ "/ft³.
Opt. Moist. = ____ %

Method of Compaction ____

Diam. Mold ____
Height Mold ____
Volume Mold ____
No. of Layers ____
Blows per Layer ____
Ht. of Free Fall ____
Wt. of Tamper ____
Shape of Tamping Face ____
Description of Sample ____

Remarks ____

Moisture Content %

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SOIL MECHANICS LABORATORY
COMPACTION TEST

PROJECT	THESIS
SITE	
SAMPLE	FINE SAND
LOCATION	McGINN PIT NO. 2
HOLE	DEPTH
TECHNICIAN R. WHITE	DATE 19 JUN 62

	Trial Number	15	16	17	18	19	20	21
Determination	Mold No.							
	Wt. Sample Wet + Mold gm	1797.0	1802.1	1804.9	1810.0	1805.2	1811.1	1809.5
	Wt. Mold gm	1421.0	1421.0	1421.0	1421.0	1421.0	1421.0	1421.0
	Wt. Sample Wet gm	376.0	381.1	383.9	389.0	384.2	390.1	388.5
	Volume Mold cu.ft.	.00726	.00726	.00726	.00726	.00726	.00726	.00726
	Wet Unit Weight lb./ft^3	114.2	115.6	116.5	118.0	116.8	118.5	118.1
	Dry Unit Weight lb./ft^3	97.6	98.1	97.4	98.9	98.5	100.5	100.2
Determination	Container No.	5113	5120	A220	G22	V15	V51	V56
	Wt. Sample Wet + Tare gm	163.60	178.56	194.56	188.98	191.39	173.14	181.94
	Wt. Sample Dry + Tare gm	148.48	162.97	174.39	169.67	171.76	157.39	163.46
	Wt. Water gm	15.12	15.59	20.17	19.31	19.63	15.75	18.48
	Tare Container gm	60.40	75.19	71.93	69.49	66.05	69.85	59.92
	Wt. Dry Soil gm	88.08	87.78	102.46	100.18	105.71	87.54	103.54
	Moisture Content %	17.2	17.8	19.7	19.3	18.6	18.0	17.8

Max. Unit Wt. = ____ "/ft^3
Opt. Moist. = ____ %

Unit Weight lb/ft^3

Moisture Content %

Method of Compaction ____

Diam. Mold ____
Height Mold ____
Volume Mold ____
No. of Layers ____
Blows per Layer ____
Ht. of Free Fall ____
Wt. of Tamper ____
Shape of Tamping Face ____
Description of Sample ____

Remarks ____

APPENDIX B

SAMPLE DATA SHEETS

Unconfined compression test data sheet

Summary and absorption data sheet

UNCONFINED COMPRESSION TEST

Machine - Soil Test Model CN 472 Date 2 Aug 62

Technician R. White

Sample Description -

4% MC 3 - 15% Water
Cured 24 hours at 110°F
Immersed 14 days

		203	207	209
Sample No.		203	207	209
Diameter	ins.	1.993	1.999	1.991
Height	ins.	3.999	3.978	3.981
Wt.Tare ≠ Sand ≠ Residual ≠ Volatiles	gm	439.03	435.92	440.02
Wt.Tare ≠ Sand ≠ Residual	gm	387.61	385.67	389.00
Wt.Tare	gm	46.05	42.97	45.55
Wt.Sand ≠ Residual	gm	341.56	342.70	343.45
Wt.Volatiles	gm	51.42	50.25	51.02
Volatile Content	%	15.05	14.65	14.87

Sample 203		Sample 207		Sample 209	
Load Dial	Strain Dial(in)	Load Dial	Strain Dial(in)	Load Dial	Strain Dial(in)
0	.190	0	.190	0	.185
.0072	.195	.0072	.195		
.0102	.200	.0087	.200		
.0132	.205	.0112	.205		
.0157	.210	.0137	.210		
.0182	.215	.0157	.215		
.0202	.220	.0177	.220		
.0207	.225	.0192	.225		
.0212	.230	.0197	.230		
.0217	.235	.0202	.235		
.0212	.240	.0202	.240	.0212	.240
.0212	.245	.0202	.245		
.0207	.250	.0192	.250		
.0197	.255	.0192	.255		
.0187	.260				

UNIVERSITY OF ALBERTA

DEPARTMENT OF CIVIL ENGINEERING

SOIL MECHANICS LABORATORY

Mix No. 2

Test. IMMERSION - ABSORPTION

R. C. White Date 18 Jul 62

Material Data:

Sand McGinn Pit No 2

Asphalt 4% MC 3

Water 15%

Initial (Moulding) Volatile Content:

Wet wt. and tare 108.5 gm.
Dry wt. and tare 97.5 gm.
Tare No. RCW 22-1 n22.6 gm.
Wt. volatiles 11.0 gm.
Dry wt. sand 74.9 gm.
Volatile Content 14.7 %

SAMPLE NO.	201	202	203	204	205	206	207	208	209	210	211	212
Initial (Moulded) wt	394.0	394.8	393.4	396.3	356.5	395.6	394.3	395.3	395.1	396.0	396.8	397.0
Cured Wt.	394.6	347.2	346.0	348.7	313.9	348.7	346.8	347.9	347.7	348.3	349.0	349.1
Cured Diameter ins.	2.00				2.013						2.014	
Cured Height, ins.	3.989				3.585						3.990	
Soaked wt. 1 day		352.3	351.	353.9		353.7	351.7	353.0	352.8	353.2		353.8
2		354.4	352.7	355.4		355.2	353.6	354.7	354.8	355.2		355.6
3		356.5	355.0	357.9		358.1	356.0	356.9	356.9	356.8		357.7
4		359.2	358.1	361.1		360.8	358.5	359.7	359.9	359.4		360.6
5		362.2	361.0	363.7		363.5	361.4	362.1	362.1	361.7		363.1
6		367.9	366.9	369.5		369.1	367.0	367.4	367.0	367.3		368.9
7		373.6	372.4	374.9		374.1	372.1	372.3	373.4	372.7		373.8
8			379.1	381.0			378.2	378.1	379.6	378.2		
9			383.8	385.6			382.7	382.5	384.6	383.1		
10			388.1	388.6			385.6	385.4	387.9	386.3		
11			390.0	390.0			387.6	386.7	389.5	387.6		
12			391.5	391.2			389.2	388.0	390.4	388.6		
13			392.8	392.3			389.7	388.4	391.7	389.6		
14			394.0	393.7			393.7	392.4	395.3	392.3		
15												
16				397.8				395.3		394.8		
17				399.4				397.3		396.4		
18				400.6				398.4		397.7		
19				400.9				398.9		398.1		
20												
21				403.5				401.3		400.5		
Height, ins.	3.989	3.987	3.999	3.988	3.585	3.980	3.978	3.973	3.982	3.979	3.990	3.988
Diameter ins.	2.009	2.002	1.993	1.984	2.013	1.994	2.000	1.990	1.991	1.979	2.014	2.005
Area, sq. ins.	3.17	3.145	3.119	3.092	3.173	3.122	3.142	3.111	3.113	3.077	3.174	3.155
Strain Dial	.050	.040	.045	.065	.050	.046	.050	.065	.055	.055	.050	.041
Load Dial	.1522	.0262	.0217	.0200	.1562	.0342	.0202	.0202	.0212	.0202	.1542	.0272
Unit Strain	1.25	1.0	1.13	1.63	1.40	1.15	1.25	1.64	1.38	1.38	1.25	1.0
Corrected Area	3.21	3.18	3.15	3.15	3.22	3.16	3.18	3.16	3.16	3.12	3.222	3.185
Load lb.	200	34	29	26.8	206	45	27	27	28	27	203	35
Stress, psi	62.3	10.7	9.21	8.50	63.9	14.2	8.49	8.55	8.86	8.65	63.0	11.0

Remarks:

APPENDIX C

SAMPLE CALCULATIONS

Mix Design

Unconfined Compressive Strength

Method of Calculating Voids

SAMPLE CALCULATIONS

Mix Design

Batch No. 5 -- 4% MC3 -- 9% mixing water

1. The weight of material necessary to mold 36 specimens 2 inches in diameter by 4 inches high was determined to be about thirty pounds (using an estimated wet unit weight of 115 pcf).

2. From the design mixing water content, an estimated 35 lb of air dried sand would be ample. Thirty five pounds of the sand was weighed out for the mix.

3. On the basis of the previously calculated water content of the air dried sand, the oven dry weight of sand was determined to be 15,820 gms.

4. The design mixing water content was 9% so a total of:

$.09 \times 15{,}820 \text{ gm} = 1424 \text{ gm}$ of water was required. However 80 gm of water was already in the sand so the required amount of water to add was:

$1424 \text{ gm} - 80 \text{ gm} = 1344 \text{ gm}$

5. The design amount of MC3 was:

$.04 \times 15{,}820 = 633 \text{ gm}$

Therefore this amount of heated MC3 was weighed into a container plus an extra 10 gm to allow for the material which adhered to the container. When the materials were being weighed out for the batch, the tare weights of the containers were determined before the materials were placed in them and after the materials had been poured out into the mix. The actual weights of materials were then used in determining the percentage of materials in the mix. There was little difference between the designed

weights and actual weights of the sand and water. Actual weight of MC3 added did vary from the designed amount due to the difficulty in estimating how much asphalt would adhere to the container. In the case of Batch No. 5 the actual weight of MC3 added was 628.5 gm as compared to the design weight of 633 gm.

Unconfined Compressive Strength

From the data taken during the unconfined compression testing of the samples, the maximum load dial reading and total strain in inches were determined. The failure load was obtained from the proving ring calibration chart for the maximum load dial reading. The unit strain was calculated on the basis of the original length of the specimen. The area at failure was determined from the area correction table. The unconfined compressive strength was taken as the failure load divided by the area at failure. The following calculation is based on data for Sample No. 701.

LOAD DIAL	STRAIN DIAL	TOTAL STRAIN
0	.190	0
.0172	.195	.005
.0322	.200	.010
.0490	.205	.015
.0690	.210	.020
.0900	.215	.025
.1065	.220	.030
.1314	.225	.035
.1503	.230	.040
.1692	.235	.045
.1792	.240	.050
.1662	.245	.055
.0920	.250	.060

Max. load dial = .1792
Failure load = 236 lb
Total strain = .050 in

$$\text{Unit strain} = \frac{0.05}{3.979} = .0126$$

Original diameter = 2.004 in
Corrected area = 3.19 sq in

$$\text{Compressive strength} = \frac{236 \text{ lb}}{3.19 \text{ sq in}} = \underline{74.0 \text{ psi}}$$

In preparing the plots of unconfined compressive strengths, the average of each group of 3 samples was used.

Calculation of Voids

The volume of voids was considered to be that part of the specimen not occupied by sand(that is voids in the aggregate as defined in the text). The following sample calculation is for the sample group 501 - 512.

Design MC3 content - 4%; water content - 9%

1. Average molded weight of twelve samples = 366.6 gm

2. Molding volatile content determined from volatile content sample RW 55-1:

   Wet weight + tare = 128.0 gm

   Dry weight + tare = 118.98 gm

   Tare = 23.02 gm

   Wt. volatiles = 9.02 gm

   Dry weight solids = 95.96 gm

   $$\text{Volatile content} = \frac{9.02 \times 100}{95.96} = \underline{9.39\%}$$

3. $$\text{Weight of sand} + \text{residual asphalt} = \frac{\text{molded weight}}{1 + \text{volatile content}} = \frac{366.6\text{ gm}}{1 + .0939} = \underline{335.1\text{ gm}}$$

4. From Table VI determine weight of MC3 in sample is:

   $$366.6\text{ gm} \times \frac{3.52}{100} = 12.9\text{ gm}$$

   and weight of residual asphalt is:

   $$366.6\text{ gm} \times \frac{3.52}{100} \times \frac{80}{100} = 10.2\text{ gm}$$

   and weight of asphalt volatiles is: 2.7 gm

5. Weight of sand = wt. of (sand + residual asphalt) - wt. residual asphalt

= 335.1 gm - 102 gm

= 324.9 gm

6. Volume of sand = $\dfrac{\text{weight of sand in gm}}{\text{specific gravity of sand}}$

= $\dfrac{324.9 \text{ gm}}{2.66 \text{ gm/cc}}$

= 122.1 cc

7. Volume of voids = total volume - volume of sand

= 205.5 cc - 122.1 cc

= 83.4 cc

8. Volume of volatiles in voids initially

= total weight - wt. of (sand + residual asphalt)

= 366.6 gm - 335.1 gm

= 31.5 gm

The volume of water in the voids is therefore:

= 31.5 gm - 2.7 gm

= 28.8 gm

As determined by Herrin the asphalt diluent is practically all evaporated in 24 hours at 110°F so that slight correction for obtaining the volume of water in the voids is only necessary for calculating the inital water content of the voids. The volume of water that the immersed samples absorbed was determined directly from:

Volume of water = total weight of sample - wt. of (sand + residual asphalt)

TABLE VI

PERCENT RESIDUAL ASPHALT IN SPECIMENS

Batch No.	Oven Dry Wt. Sand gm	Wt. Water gm	Wt. MC 3 gm	Total Wt. Materials in Mix gm	Water in Mix %	MC 3 in Mix %	Residual MC 3 in Mix %
1	13,552	2032	682	16,266	12.5	4.19	3.31
2	15,820	2354	640	18,814	12.5	3.40	2.69
3	"	2057	632	18,509	11.1	3.41	2.69
4	"	1749	632	18,201	9.61	3.47	2.74
5	"	1424	628	17,872	7.98	3.52	2.78
6	"	1583	320	17,723	8.93	1.81	1.43
7	"	1899	314	18,033	10.5	1.74	1.38
8	"	2210	316	18,346	12.0	1.72	1.36
9	"	2532	318	18,670	13.6	1.70	1.34
10	9,027	451	182	9,660	4.67	1.88	1.49
11	"	452	99	9,578	4.72	1.04	.822
12	6,770	678	58	7,506	9.04	.773	.611
13	"	1016	73	7,859	12.9	.936	.740
14	"	1219	73	8,062	15.1	.912	.720
15	11,284	1805	226	13,315	13.6	1.69	1.34
16	"	2031	103	13,418	15.1	.770	.608
17	"	1693	448	13,435	12.6	3.34	2.64

TABLE VII

VOIDS IN THE MINERAL AGGREGATE

MC 3 Content %	Molding Water Content %	Sample Group	Molded Volatile Content %	Molded Weight gm	Weight Sand+ Res.As. gm	Weight Residual Asphalt gm	Weight Asphalt Diluent gm	Weight Sand gm	Volume Sand cc	V.M.A. cc
4	14.35	201-212	14.7	395.3	344.6	10.6	2.8	334.0	125.5	80.0
	"	213-224	"	396.6	345.7	10.7	2.8	335.0	125.9	79.6
	14.75	225-236	15.1	397.6	345.4	"	"	334.7	125.8	79.7
4	12.9	301-312	13.05	385.7	341.1	10.4	2.8	330.7	124.3	81.2
	12.6	313-324	13.35	388.3	342.5	"	"	332.1	124.8	80.7
	13.1	325-336	13.5	389.1	342.8	10.5	"	332.3	124.9	80.6
4	11.0	401-412	11.45	375.0	336.5	10.3	2.7	326.2	122.6	82.9
	10.9	413-424	11.4	375.3	336.9	"	"	326.6	122.8	82.7
	"	425-436	11.35	375.4	337.2	10.3	"	326.9	122.9	82.6
4	8.9	501-512	9.39	366.6	335.1	10.2	2.7	324.9	122.1	83.4
	"	513-524	9.48	367.2	335.4	"	"	325.2	122.3	83.2
	"	525-536	9.48	366.4	334.7	"	"	324.5	122.0	83.5
2	10.0	601-612	10.24	363.6	329.8	5.2	1.4	324.6	122.0	83.5
	10.1	613-624	10.33	361.9	328.0	"	"	322.8	121.4	84.1
	10.1	625-636	10.35	363.0	329.0	"	"	323.8	121.7	83.8
2	11.9	701-712	12.13	372.1	331.8	5.1	1.4	326.7	122.8	82.7
	12.0	713-724	12.2	370.3	330.0	"	"	324.9	122.1	83.4
	11.8	725-736	12.0	373.0	333.0	"	"	327.9	123.3	82.2
2	14.0	801-812	14.25	383.9	336.0	5.2	1.4	330.8	124.4	81.1
	13.9	813-824	14.05	381.1	333.8	"	"	328.6	123.5	82.0
	13.7	825-836	14.2	381.2	334.7	"	"	329.5	123.9	81.6

TABLE VII (continued)

MC 3 Content	Molding Water Content	Sample Group	Molded Volatile Content	Molded Weight	Weight Sand + Res.As.	Weight Residual Asphalt	Weight Asphalt Diluent	Weight Sand	Volume Sand	V.M.A.
%	%		%	gm	gm	gm	gm	gm	cc	cc
2	16.1	901-912	16.3	391.7	336.8	5.2	1.4	331.6	124.7	80.8
	15.8	913-924	16.0	391.6	337.6	"	"	332.4	125.0	80.5
	"	925-936	15.95	390.8	337.0	"	"	331.8	124.7	80.8
2	5.2	1001-1006	5.55	341.3	323.3	5.1	1.4	319.5	119.6	85.9
	"	1007-1012	"	341.8	323.8	"	"	321.1	119.8	85.7
1	5.0	1101-1106	5.2	339.1	322.3	2.8	.7	319.5	120.1	85.4
	"	1107-1112	"	340.7	323.9	"	"	321.1	120.7	84.8
1	9.8	1201-1206	9.85	357.5	325.4	2.2	.6	323.2	121.5	84.0
	"	1207-1212	"	358.0	325.9	"	"	323.7	121.7	83.8
1	14.8	1301-1306	14.9	382.9	333.2	2.8	.7	330.4	124.2	81.3
	"	1307-1312	"	384.2	334.4	"	"	331.6	124.7	80.8
1	17.6	1401-1406	17.6	393.5	334.6	2.8	.7	331.8	124.7	80.8
	"	1407-1412	"	392.8	334.0	"	"	331.2	124.5	81.0
1	13.6	1601-1606	13.65	375.4	330.3	2.3	.6	328.0	123.3	82.2
	"	1607-1612*	"	358.0	315.0	2.2	"	312.8	117.6	78.0
	9.6	1613-1618	9.56	355.0	324.0	"	"	321.8	121.0	84.5
	"	1619-1624	"	356.5	325.4	"	"	323.2	121.5	84.0
2	9.5	1501-1506	9.73	361.9	329.8	4.8	1.3	325.0	122.2	83.3
	"	1507-1512	"	364.3	332.0	4.9	"	327.1	123.0	82.5
	10.2	1513-1518	10.4	370.3	335.4	"	"	330.5	124.2	81.3
	"	1519-1524	"	371.7	336.7	5.0	"	331.7	124.7	80.8
4	12.2	1701-1706	12.6	378.5	336.1	10.0	2.7	326.1	122.6	82.9
	"	1707-1712	"	376.5	334.4	9.9	2.6	324.5	122.0	83.5
	9.4	1713-1718	9.87	363.5	330.8	9.6	2.5	321.2	120.8	84.7
	"	1719-1724	"	363.1	330.5	"	"	320.9	120.6	84.9

* This test series contained a short sample. Total ave. volume = 195.6 cc

TABLE VIII

RESIDUAL ASPHALT CONTENT AND COMPRESSIVE STRENGTH

MC 3 Content %	Molding Water Content %	Curing Period hrs	V.M.A. Filled with Residual Asphalt %	Compressive Strength After Curing psi
1	10	24	2.62	88
2	"	"	6.23	67
4	"	"	12.3	42
2	"	72	6.19	75
4	"	"	12.4	46
1	"	120	2.62	113
2	"	"	6.20	73
4	"	"	12.4	47
1	12	24	3.0	99
2	"	"	6.17	76
4	"	"	12.6	56
2	"	72	6.12	77
4	"	"	12.7	54
1	"	120	3.0	133
2	"	"	6.21	94
4	"	"	12.8	56
1	14	24	3.44	101
2	"	"	6.41	80
4	"	"	13.3	64
2	"	72	6.35	87
4	"	"	13.5	66
1	"	120	3.46	143
2	"	"	6.37	97
4	"	"	13.5	71
		Following samples aerated		
1	10	24	2.7	69
2	"	"	6.0	43
4	"	"	11.3	39
1	"	120	2.7	86
2	"	"	6.0	58
4	"	"	11.3	41
1	12	24	2.7	85
4	"	"	12.0	44
1	"	120	2.7	107
4	"	"	12.0	52

APPENDIX D

RATES OF WATER ABSORPTION

Curves showing rates of water absorption by the various mixtures based on the percent of voids in the aggregate filled with water.

Figure 27

RATE OF WATER ABSORPTION

1% CUTBACK - 5.0% MOLDING WATER

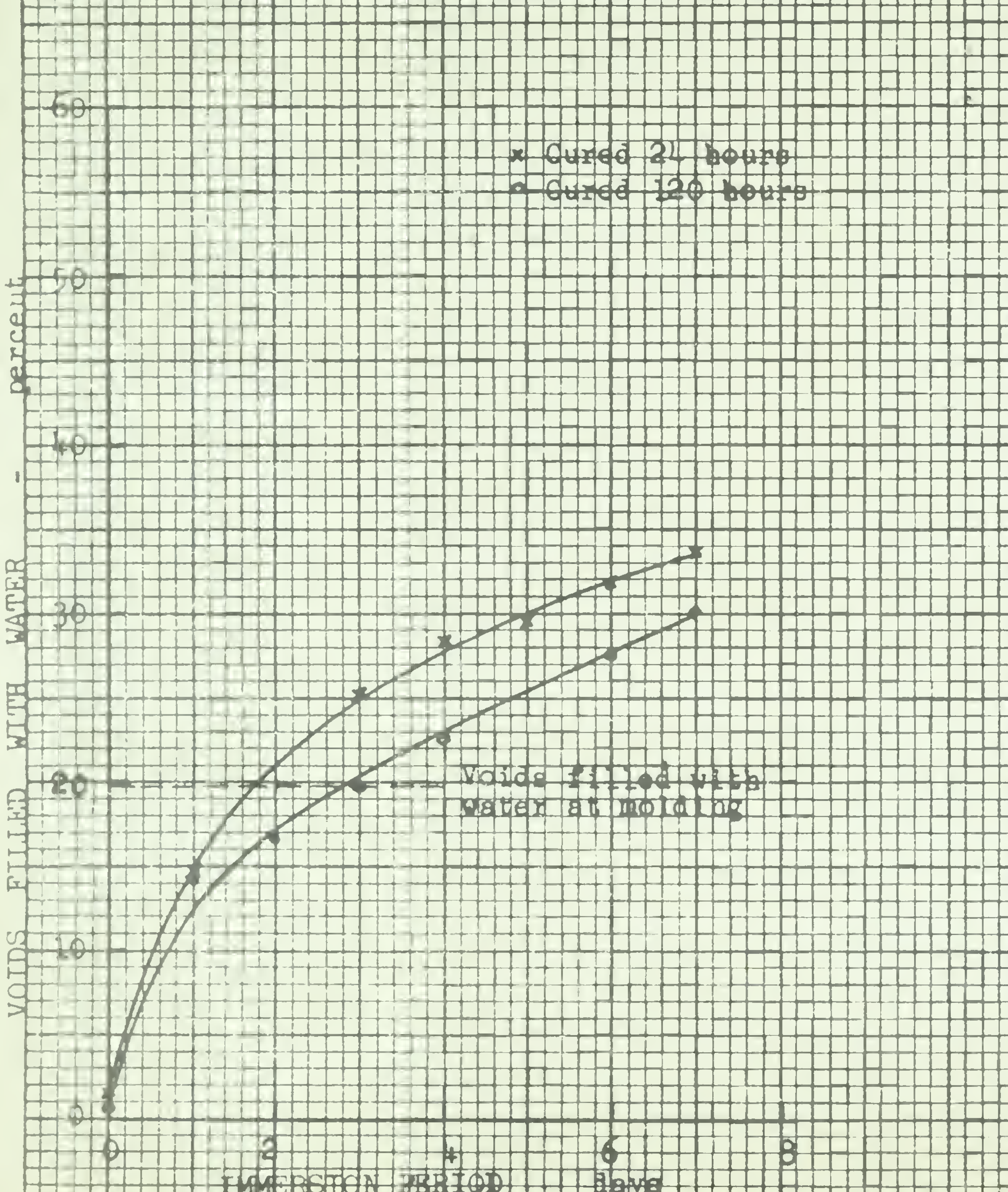


Figure 26

RATE OF WATER ABSORPTION

1% CUTBACK - 9.8% MOLDING WATER

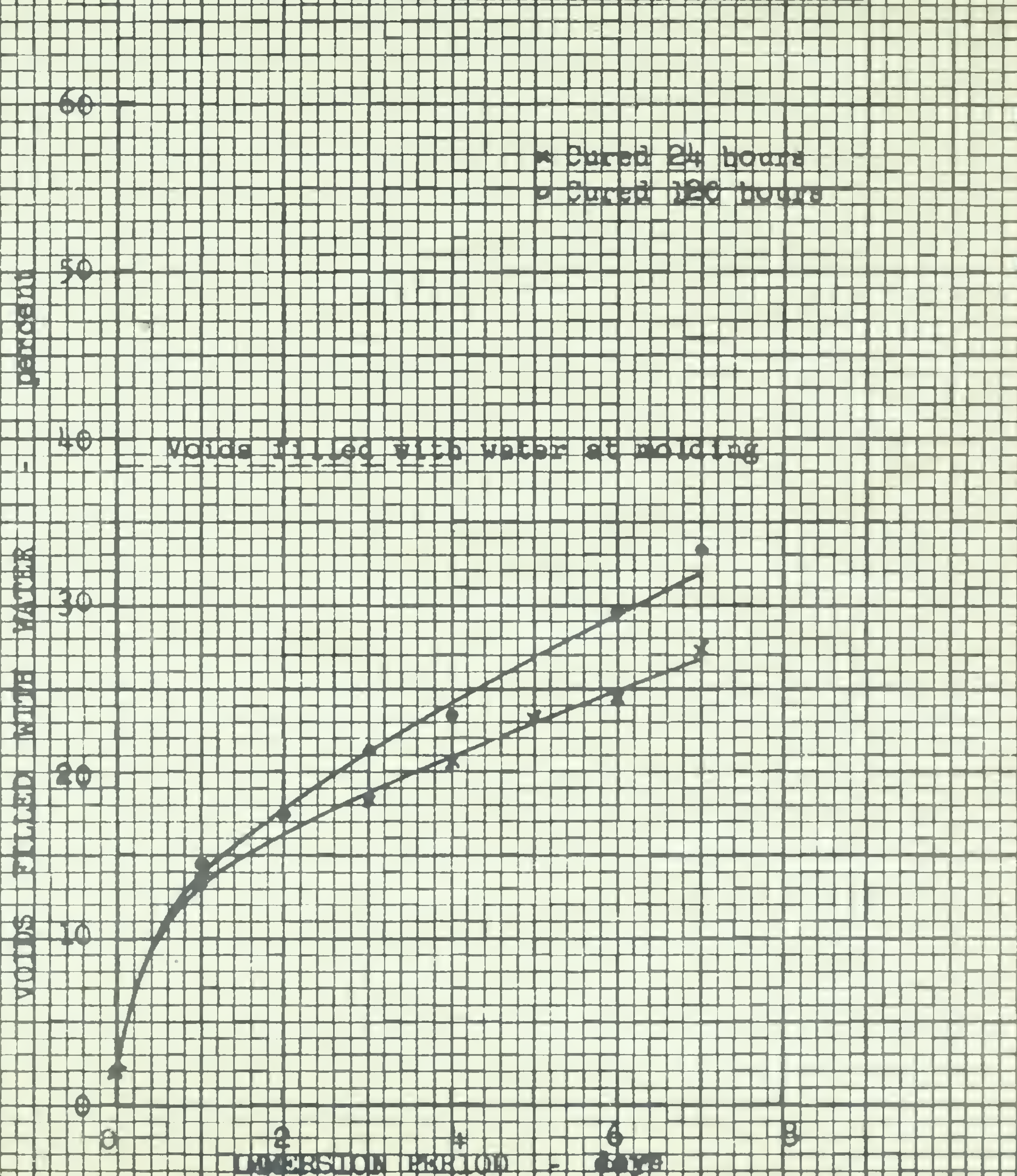


Figure 29

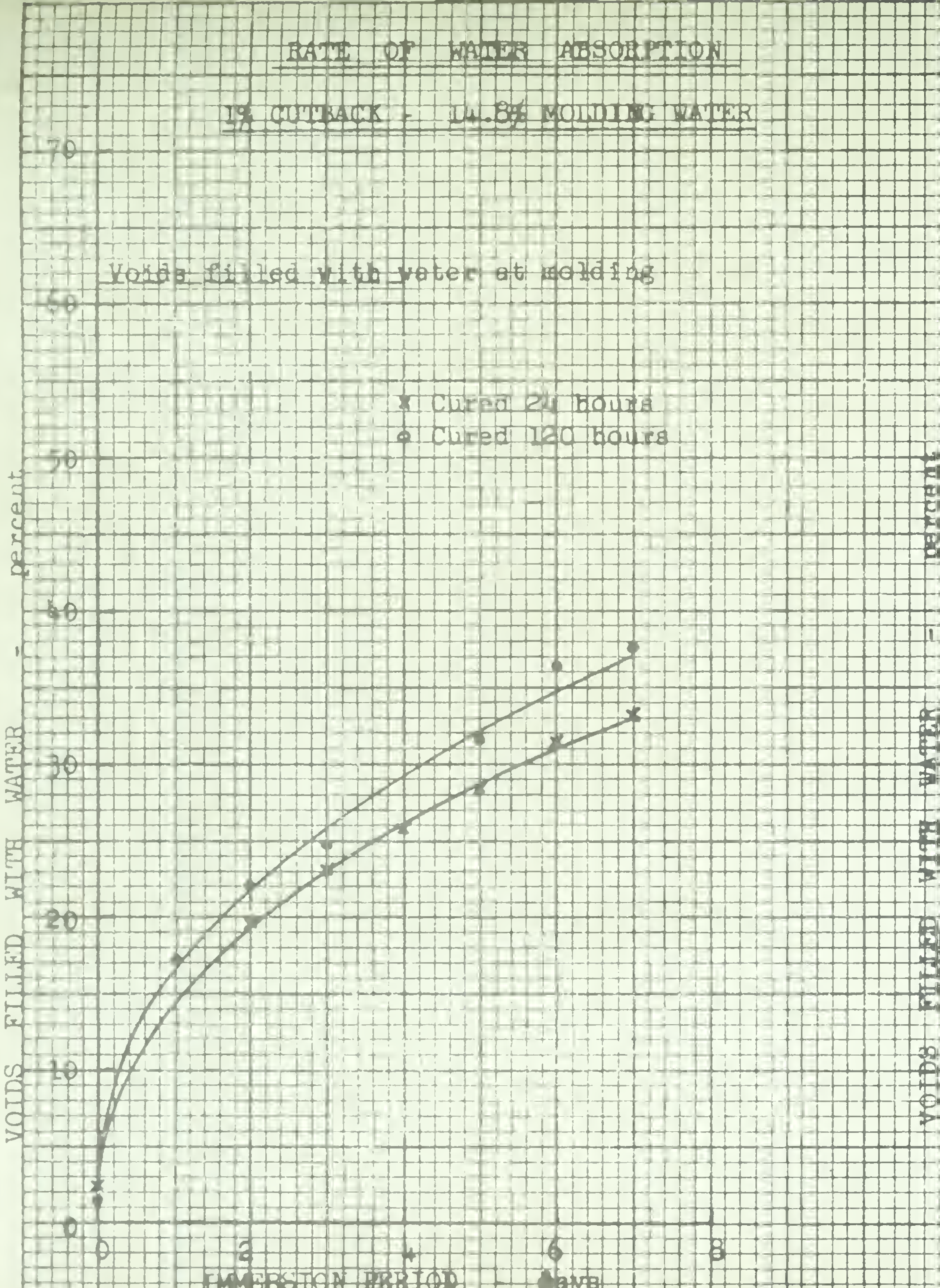
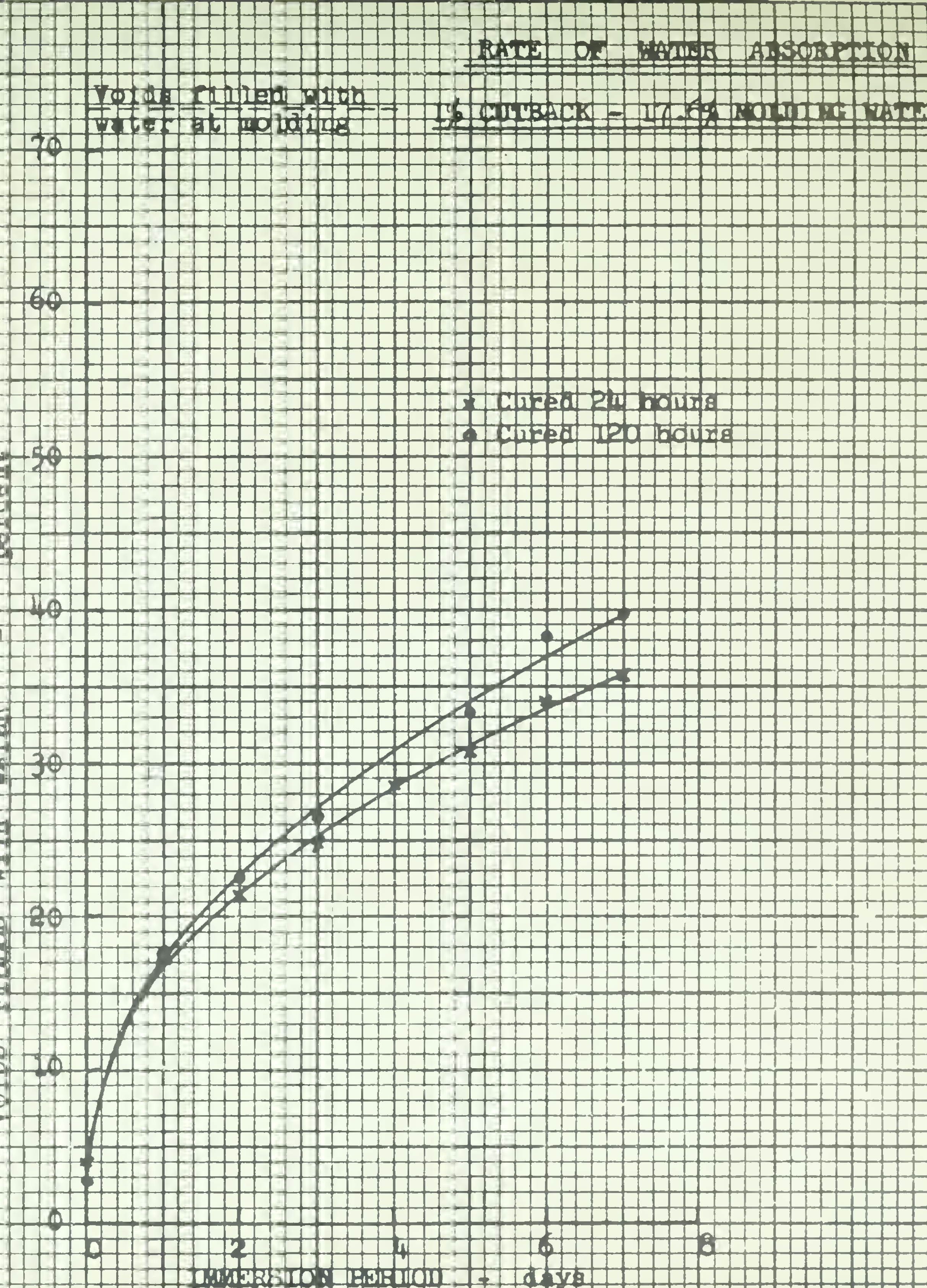


Figure 30



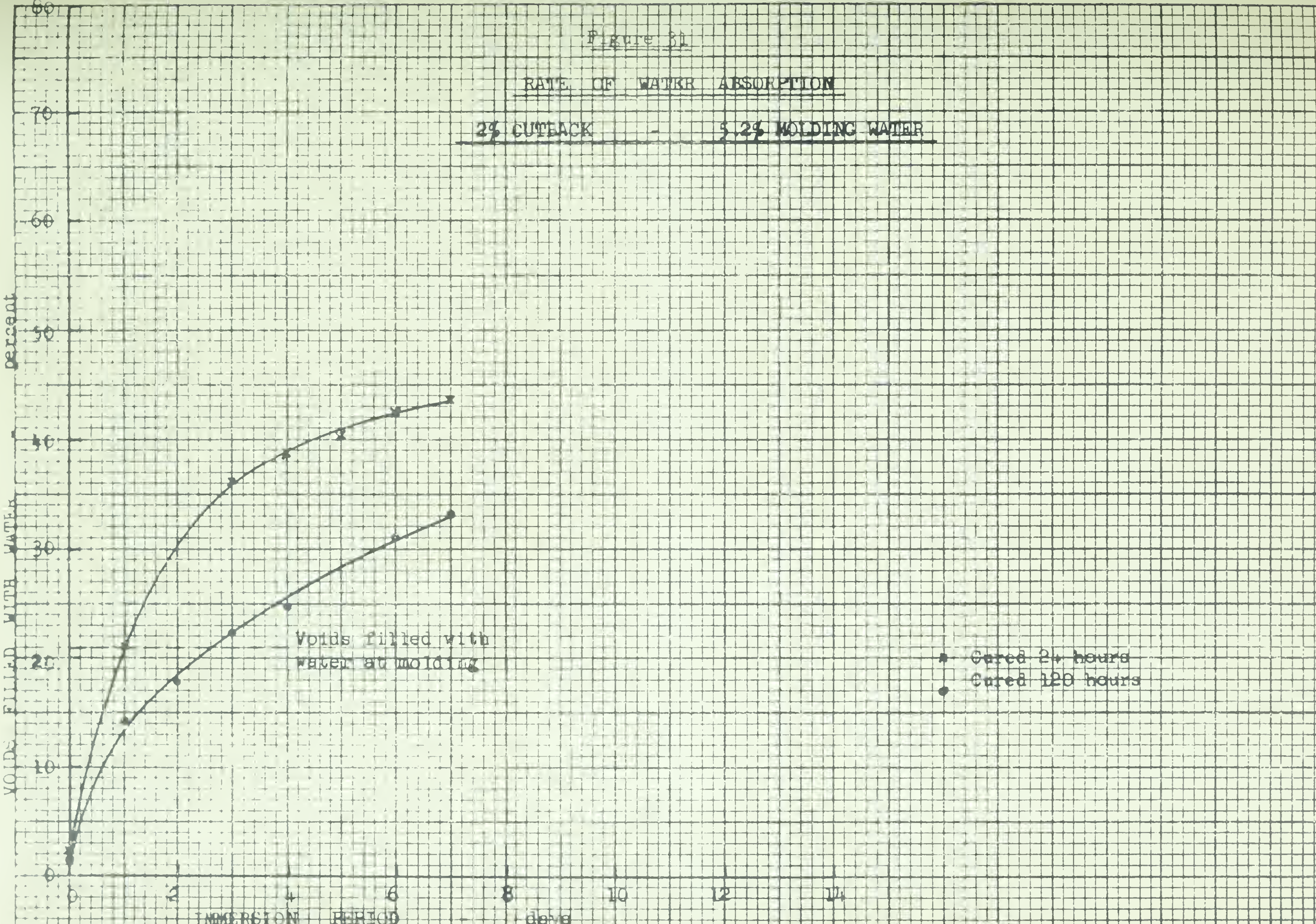


Figure 31

RATE OF WATER ABSORPTION

2% CUTBACK - 5.2% MOLDING WATER

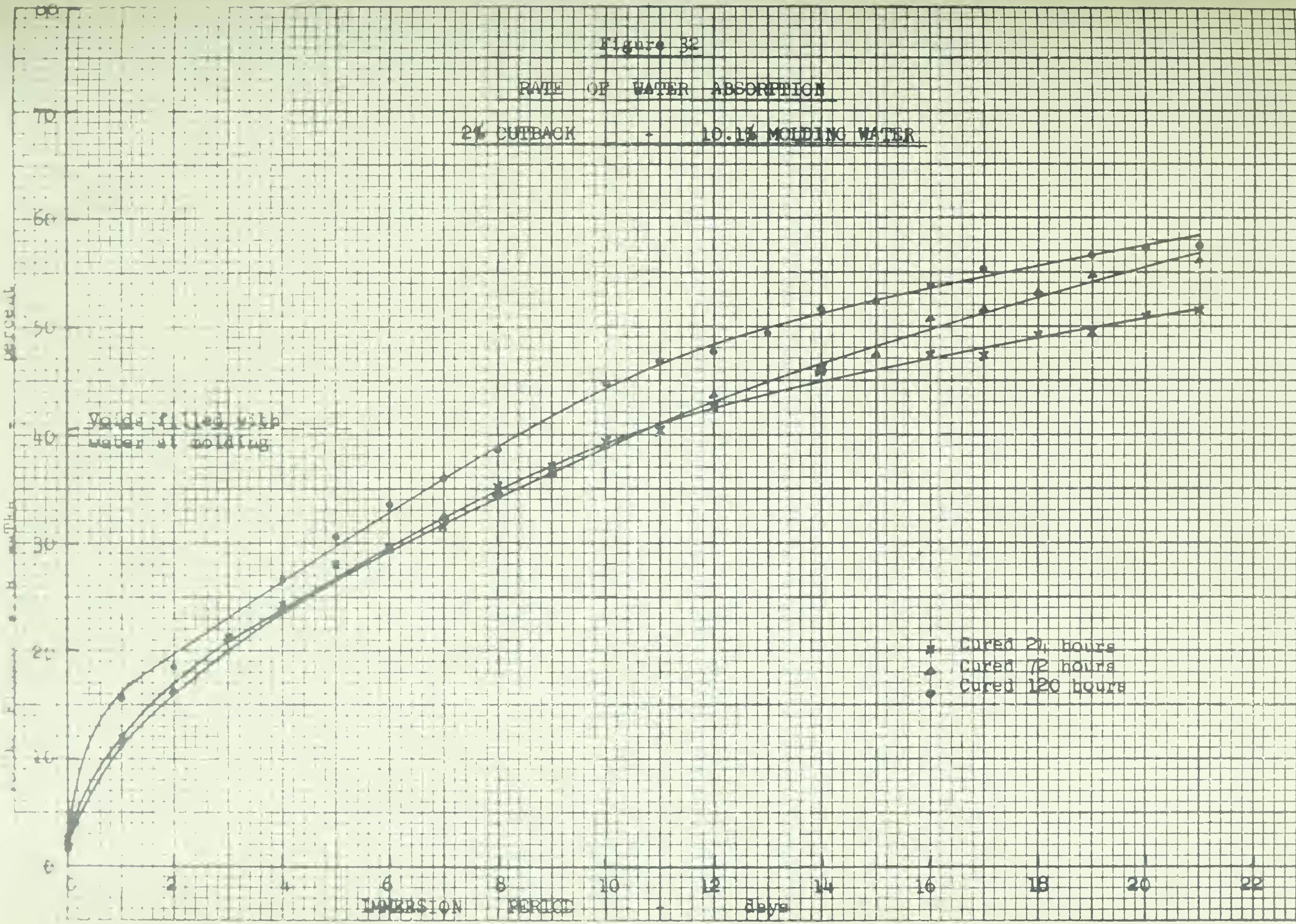


Figure 32

RATE OF WATER ABSORPTION

2% CUTBACK - 10.1% MOLDING WATER

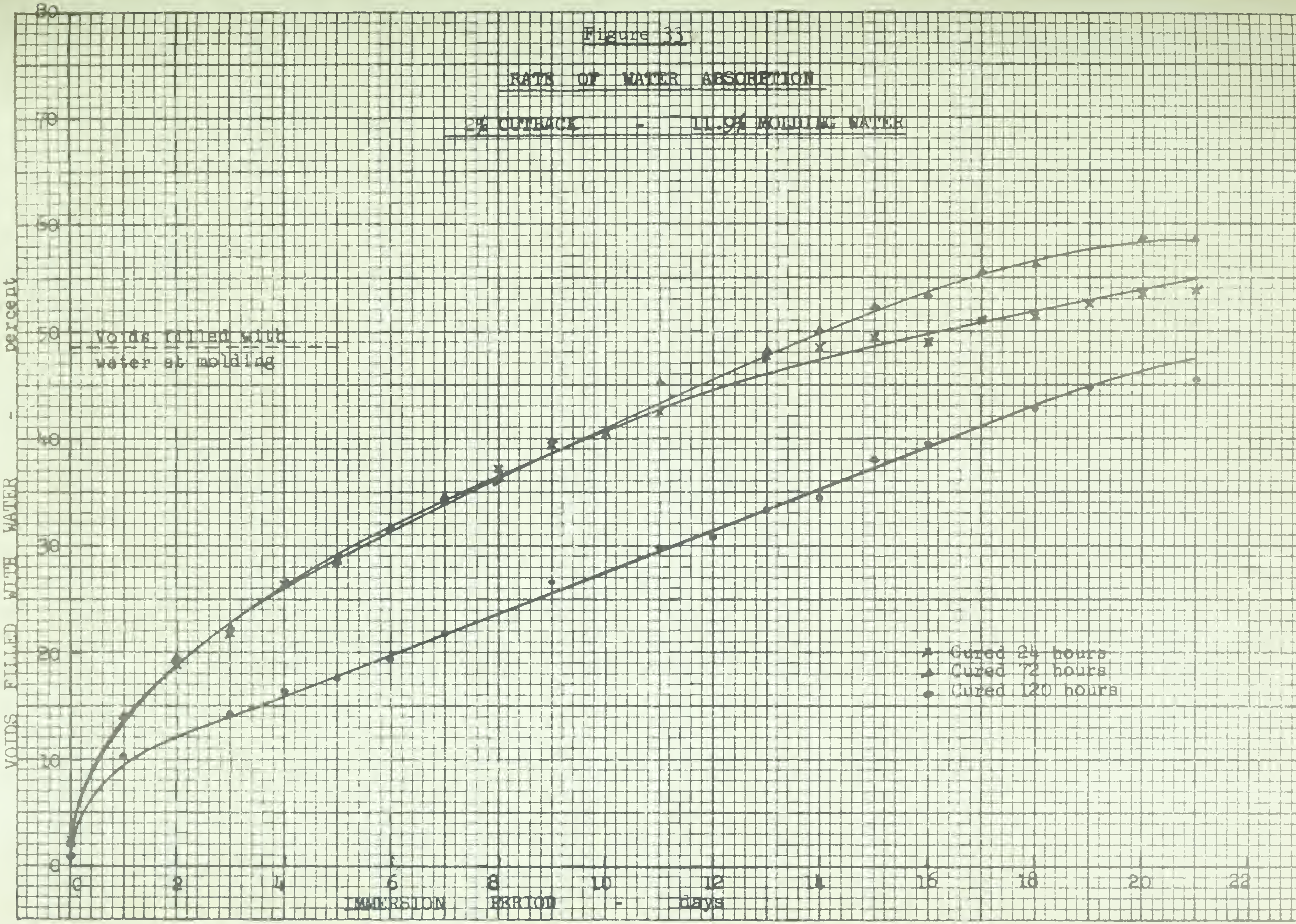


Figure 33
RATE OF WATER ABSORPTION
2% CUTBACK - 11.9% MOLDING WATER
VOIDS FILLED WITH WATER - percent
IMMERSION PERIOD - days
Voids filled with
water at molding
Cured 24 hours
Cured 72 hours
Cured 120 hours
0
10
20
30
40
50
60
70
80
0
2
4
6
8
10
12
14
16
18
20
22

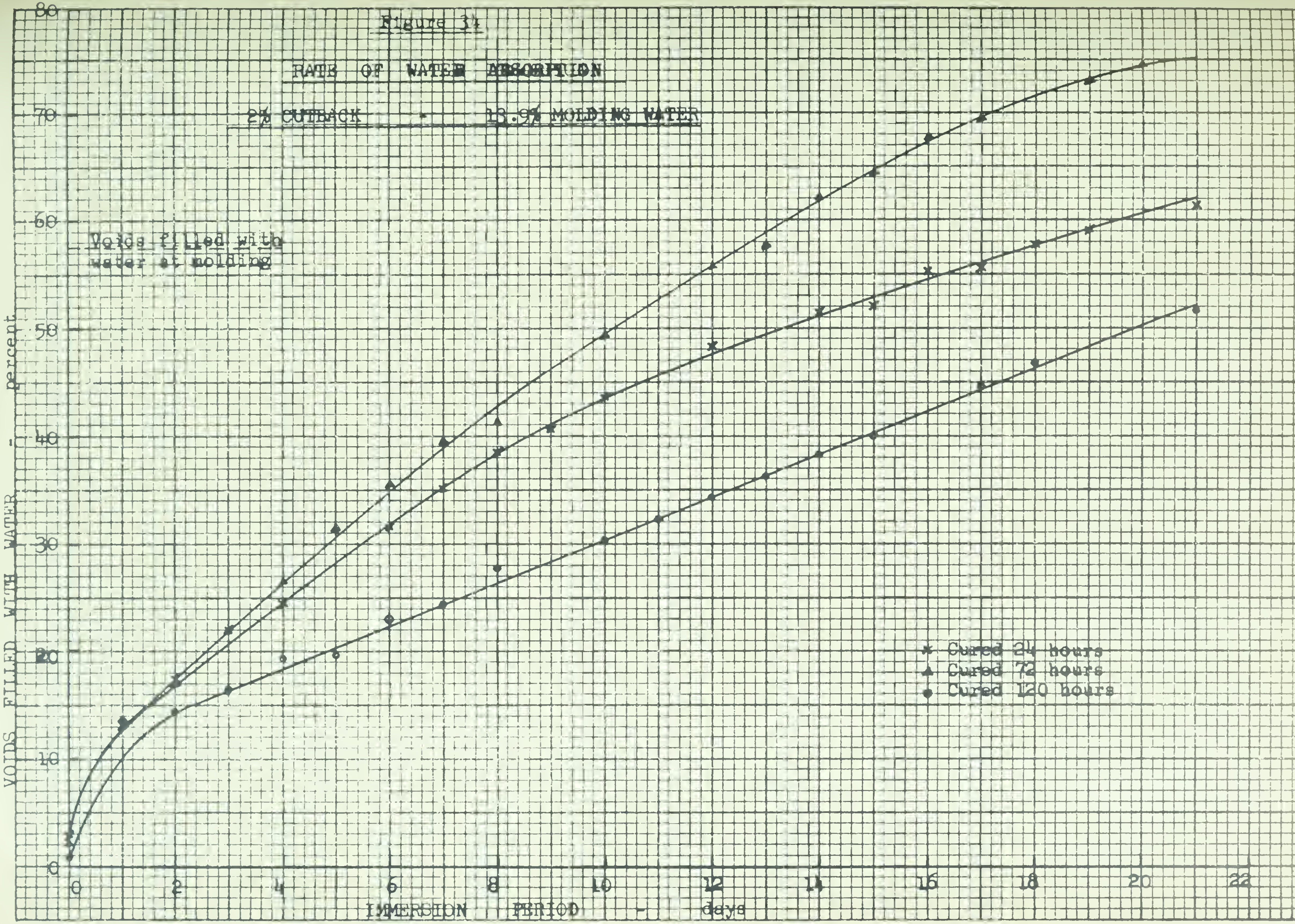


Figure 34

RATE OF WATER ABSORPTION

2% CUTBACK - 13.9% MOLDING WATER

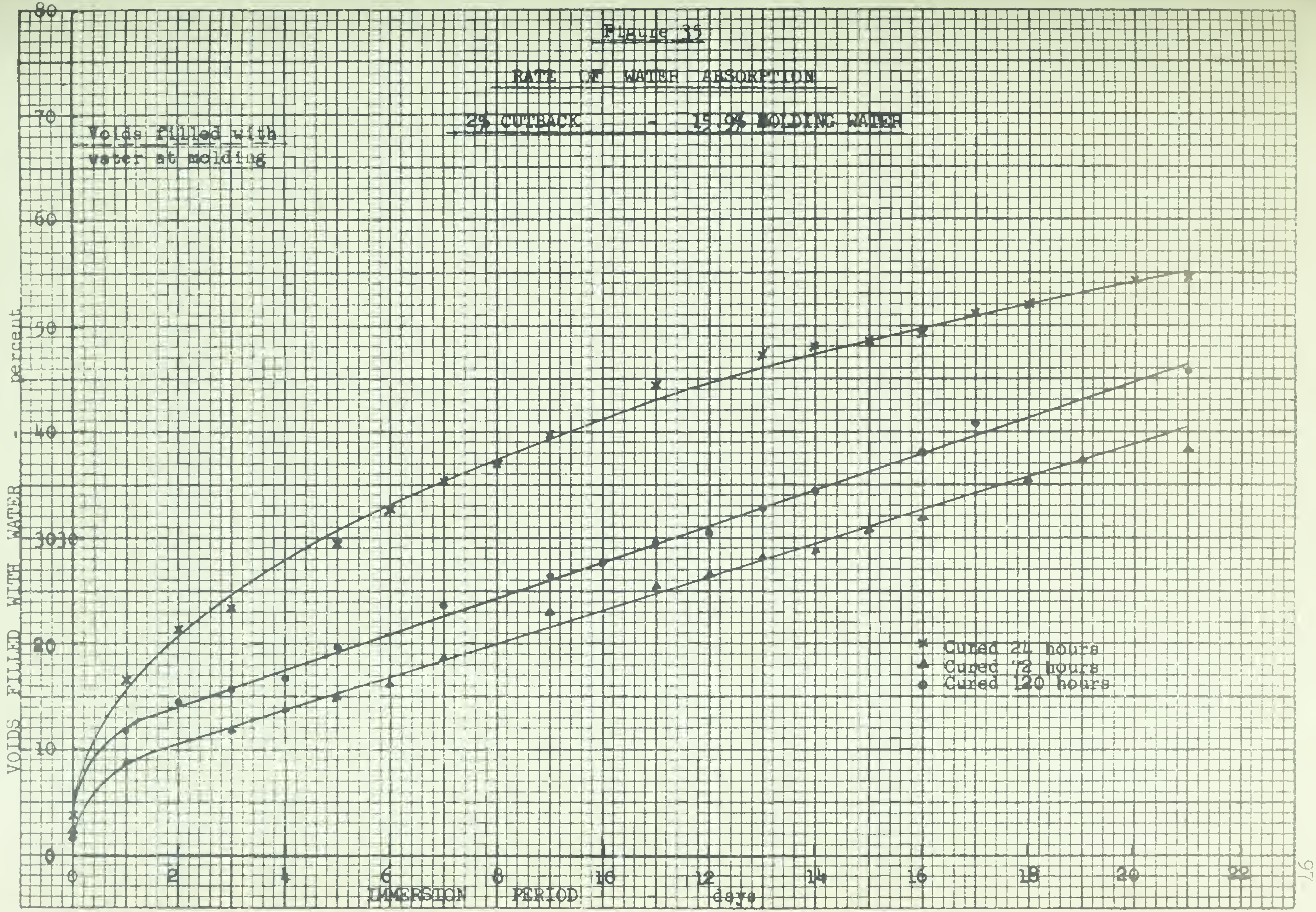


Figure 35

RATE OF WATER ABSORPTION

2% CUTBACK - 15.9% MOLDING WATER

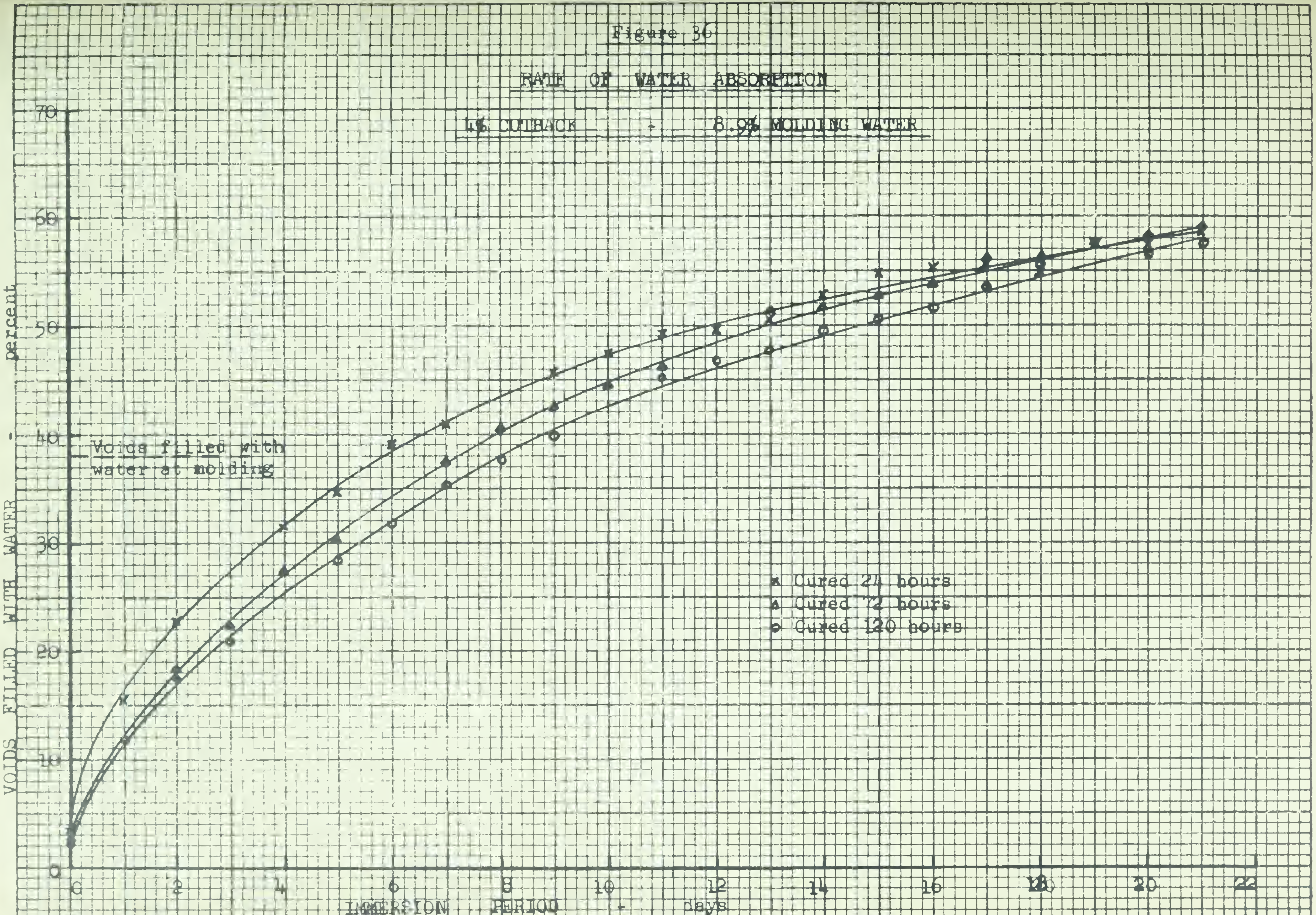


Figure 36
RATE OF WATER ABSORPTION
4% CUTBACK - 8.9% MOLDING WATER
Voids filled with water at molding
Cured 24 hours
Cured 72 hours
Cured 120 hours
VOIDS FILLED WITH WATER - percent
IMMERSION PERIOD - days
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20
22

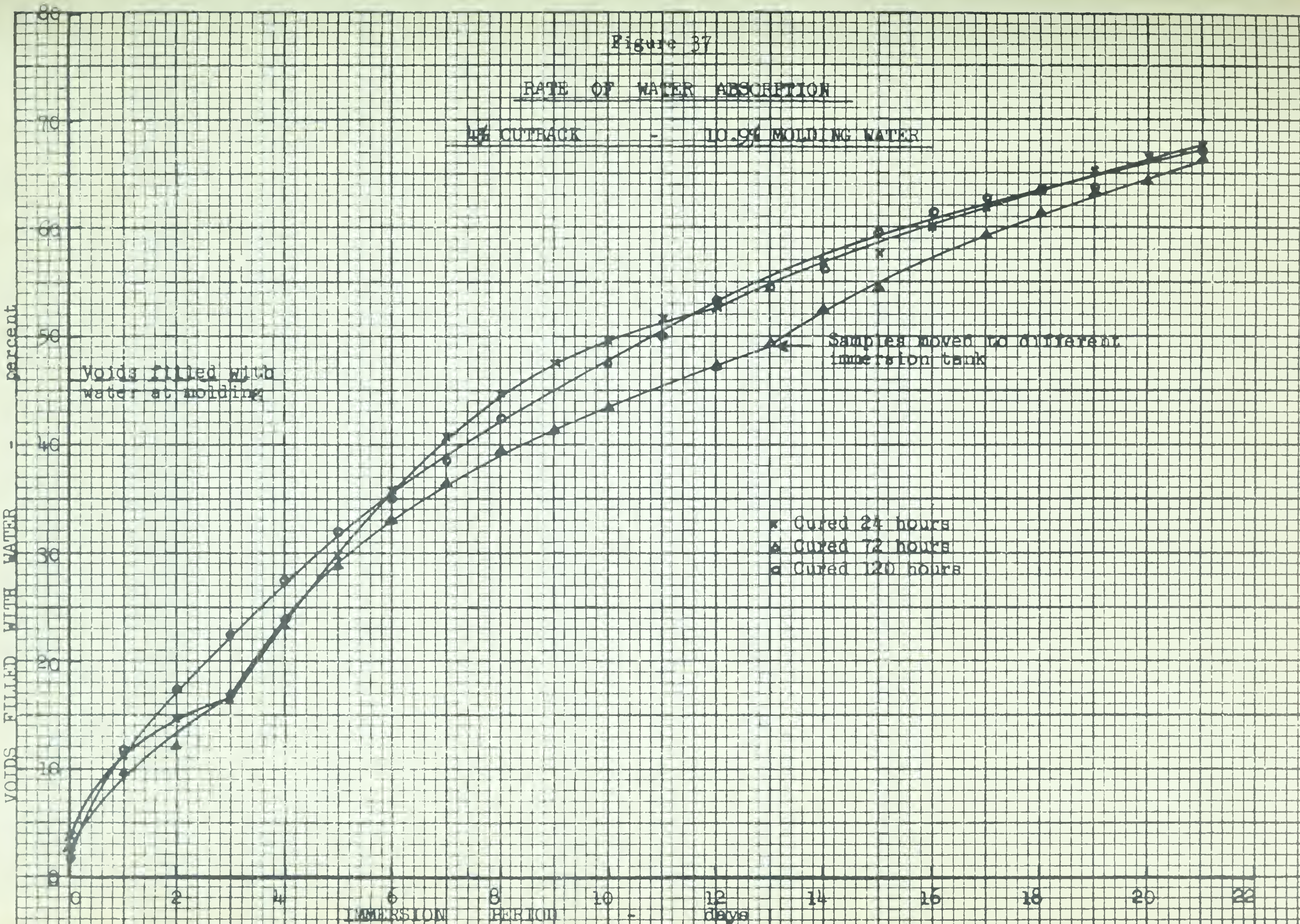


Figure 37

RATE OF WATER ABSORPTION

4% CUTBACK - 10.9% MOLDING WATER

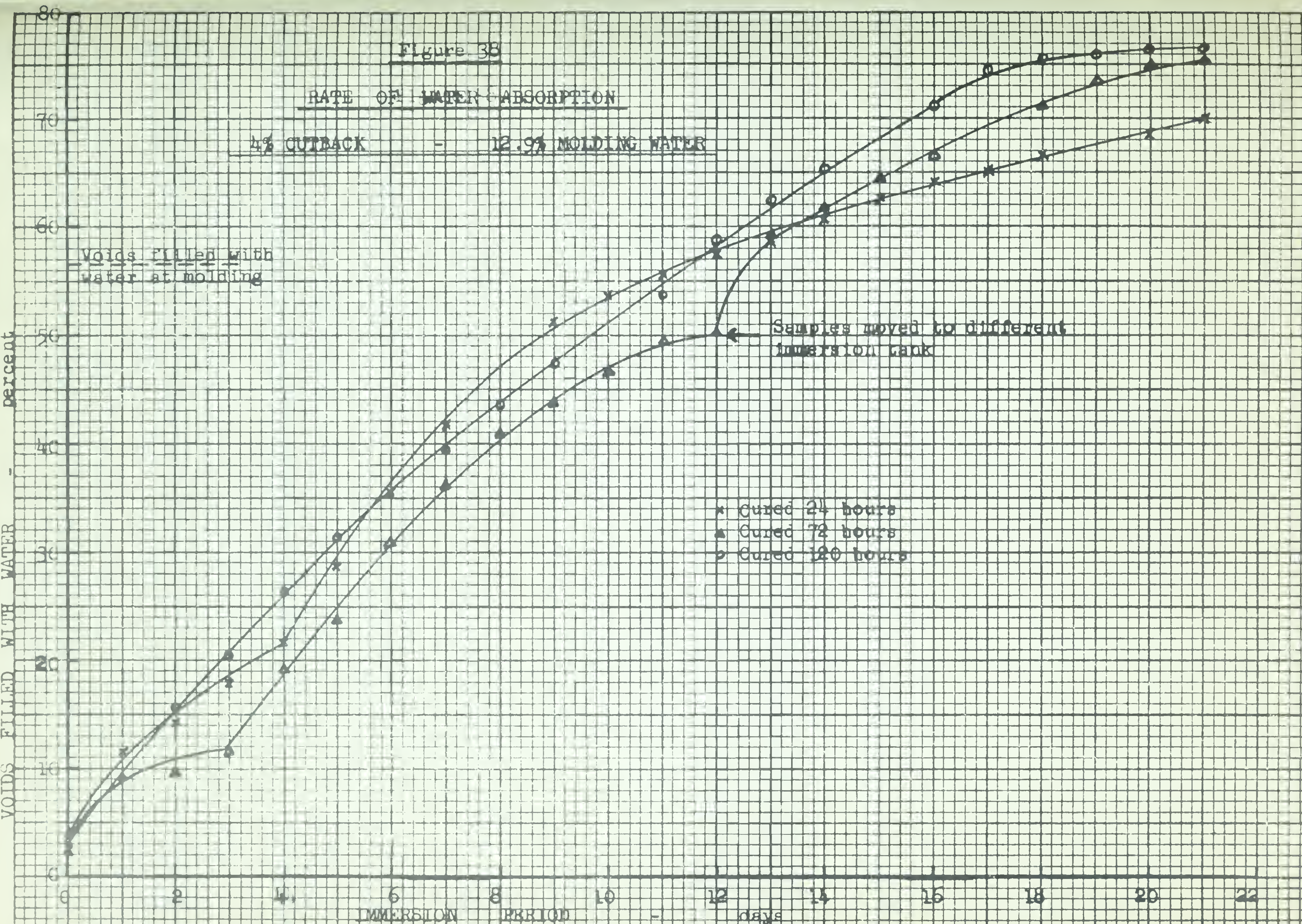


Figure 38
RATE OF WATER ABSORPTION
4% CUTBACK - 12.9% MOLDING WATER
Voids filled with water at molding
Samples moved to different immersion tank
× Cured 24 hours
▲ Cured 72 hours
○ Cured 120 hours
VOIDS FILLED WITH WATER - percent
IMMERSION PERIOD - days
0
10
20
30
40
50
60
70
80
0
2
4
6
8
10
12
14
16
18
20
22

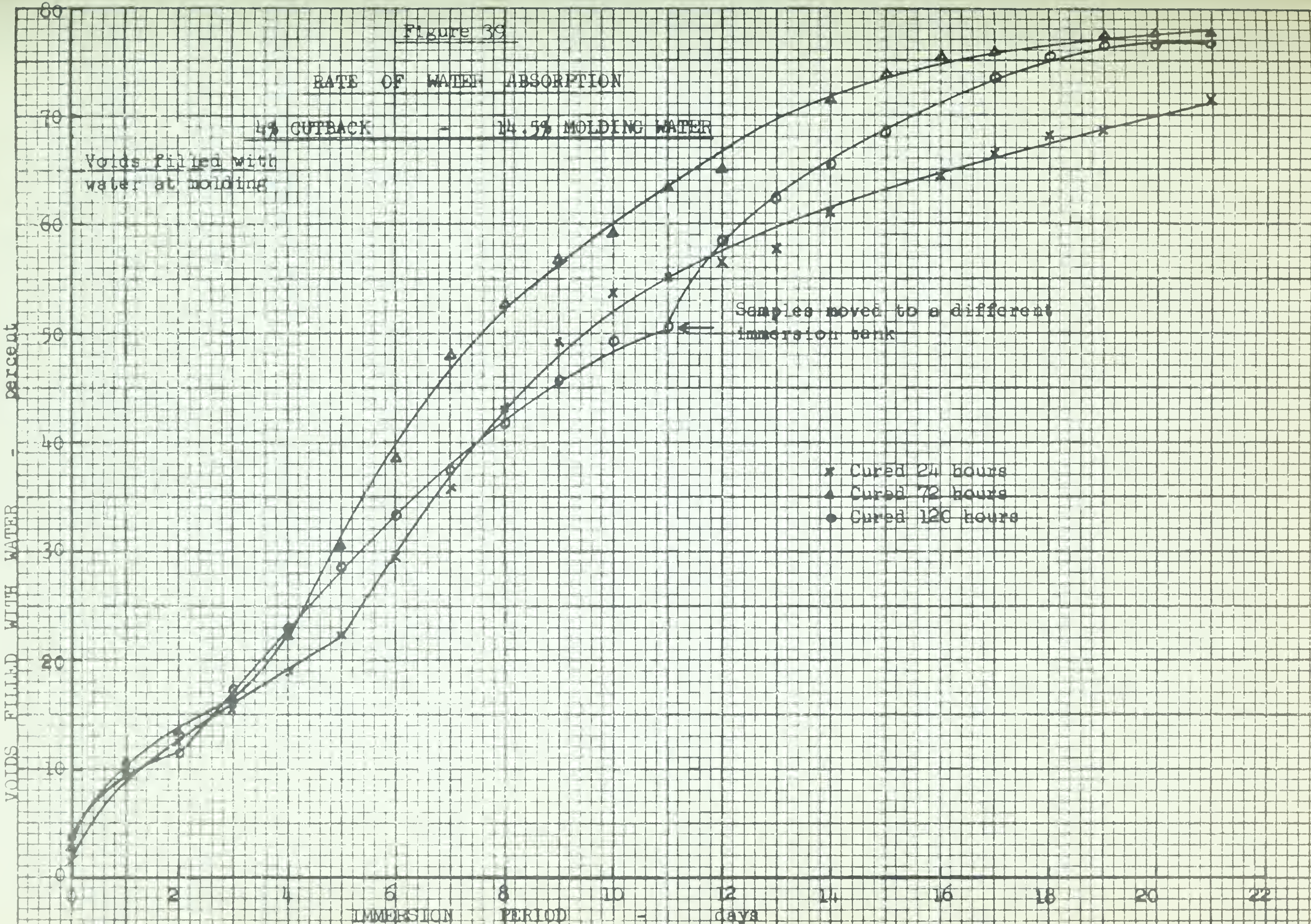


Figure 39

RATE OF WATER ABSORPTION

4% CUTBACK - 14.5% MOLDING WATER

Figure 40

RATE OF WATER ABSORPTION

MIXING CUTBACK CONTENT 1% - MIXING WATER CONTENT 18%

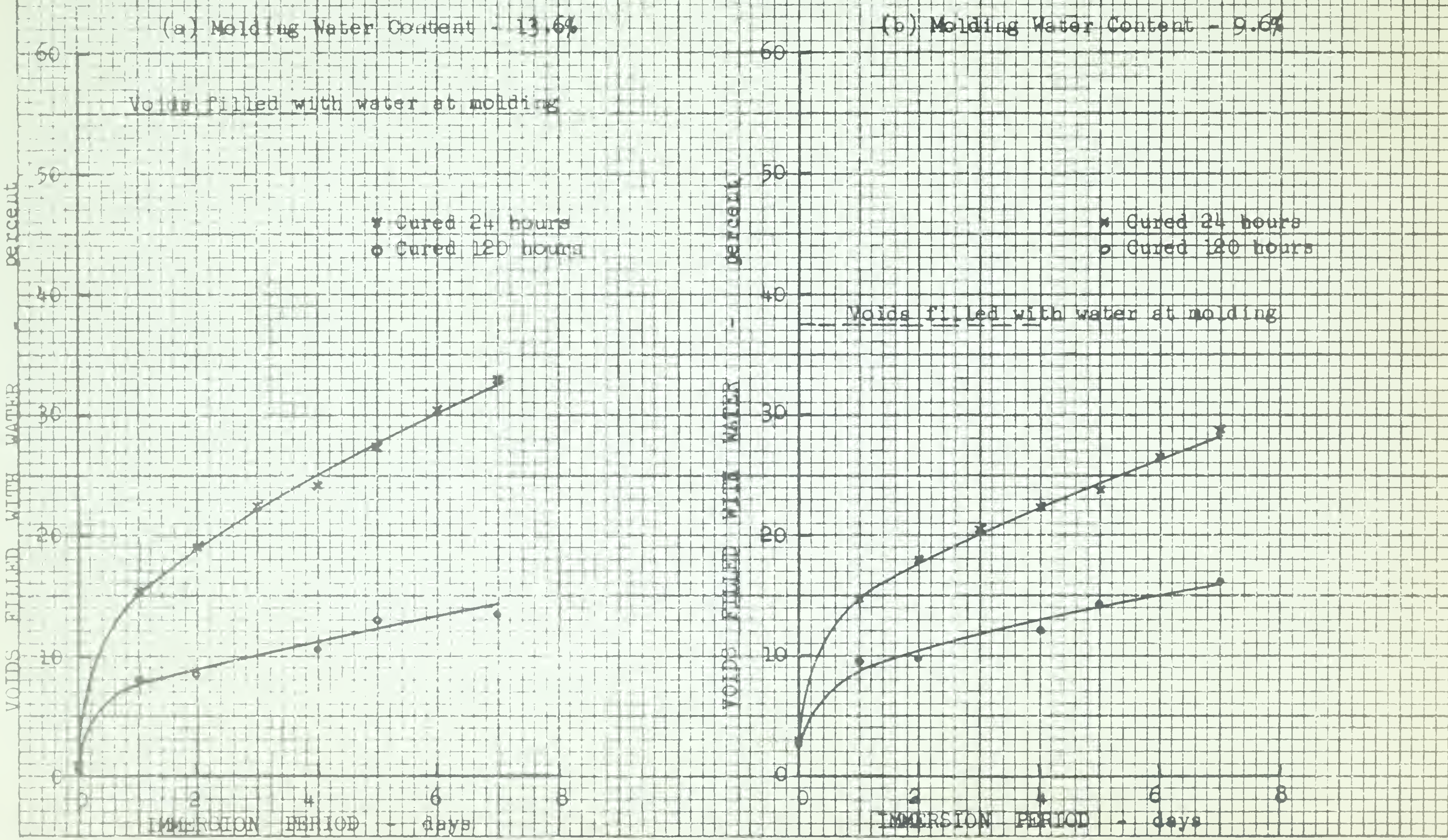
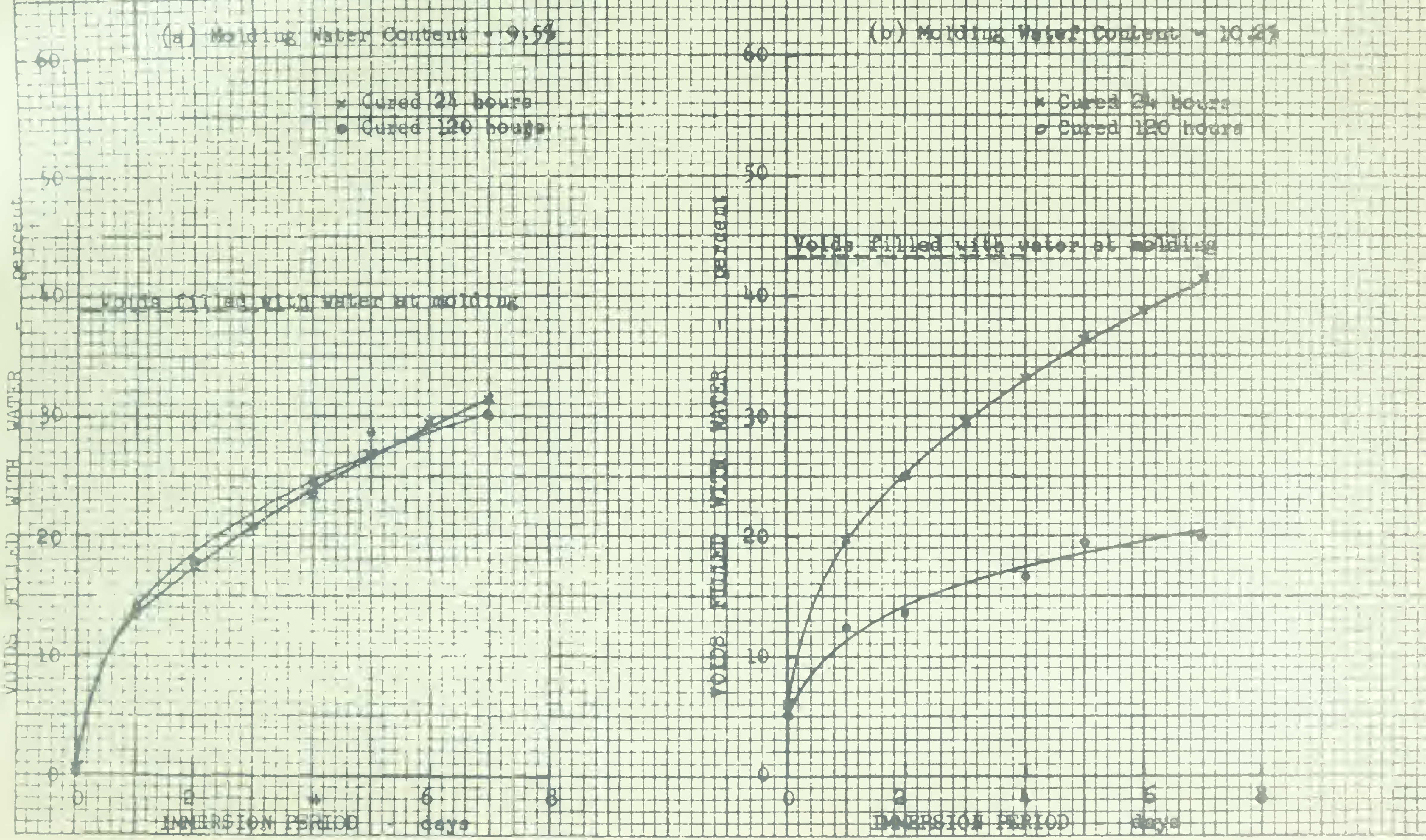


Figure 41

RATE OF WATER ABSORPTION

MIXING CUTBACK CONTENT 2% - MIXING WATER CONTENT 15.9%



RATE OF WATER ABSORPTION

MIXING CUTBACK CONTENT 4% - MIXING WATER CONTENT 11.4%